© 2016 IJSRSET | Volume 2 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Assessment of Advanced High Strength Steels used in Auto Industry – A Review

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ABSTRACT

Advanced High Strength Steels (AHSS) are steels considered to be the major materials for future applications in automotive production and other sectors of the economy. In this article, assessment of advanced high strength steels (AHSS) used in automotive industry was discussed, including the steel compositions, microstructure and mechanical properties developed during thermal processing, advantages and disadvantages, their potential applications and performance in service. Various strengthening mechanisms are employed to achieve a range of strength, ductility, toughness, and fatigue properties of these materials. As opposed to the cold formable single phase deep-drawable grades, the mechanical properties of AHSS steels are controlled by many factors, including the following; phase composition and distribution in the overall microstructure, volume fraction, size and morphology of phase constituents, as well as stability of metastable constituents were discussed. Finally, a brief summary of these important steels was highlighted.

Keywords: A*dvanced High Strength Steels, Automobile Industry, Microstructure, Mechanical Properties.*

I. INTRODUCTION

Since the birth of the automotive industry in 1886 by Karl Benz, the automakers have being facing many challenges because of the competitions in that sector. As explained by Carrie, (2011), automakers are challenged to improve safety and fuel economy. As a result of that, they search for new materials to meet higher standards of their products. Carrie, (2011) also explained that, advanced high-strength steels (AHSS) help engineers meet requirements for safety, efficiency, emissions, manufacturability, durability, and quality at a low cost. AHSS are a newer generation of steel grades that provide extremely high-strength and other advantageous properties, while maintaining the high formability required for manufacturing. It was well known that AHSS have been on the road for many years, but with additional research and development, automakers are using these newer grades in more applications. According to Jody, (2011), in today's heavily regulated and highly competitive marketplace, automotive industries have been faced with many challenges among which are: greater vehicle safety, improved fuel economy and lower manufacturing costs and reduction of green house emission. One approach to help resolve these issues has been to develop structural materials that are lightweight, while still offering strength and flexibility. Among recent technological advances, Advanced High Strength Steels or AHSS have quickly been adopted by the automobile industry. As explained by Alan (2006), and Savkin et al, (2014), advanced high strength steels are complex, sophisticated materials, with carefully selected chemical compositions and multiphase microstructures resulting from precisely controlled heating and cooling processes. These steels are known for their increased strength, lightweight composition, and improved performance under impact and energy transfer when exposed to a collision.

According to the International Iron and Steel Institute (2006), automotive steels can be classified in several different ways. Common designations include low-strength steels (interstitial-free and mild steels); conventional HSS (carbon-manganese, bake hardenable, high-strength interstitial-free, and high-strength, low-alloy steels); and newer types of Advanced High Strength Steels (AHSS), typically classified by microstructure at room temperature. These AHSS include dual phase, transformation-induced plasticity, complex phase, and martensitic steels. A second classification method important to part designers is strength of the steel, since steel alloys have virtually the same density and elastic modulus throughout strength ranges. One such system defines High-Strength Steels (HSS) as yield strengths from 210 to 550 MPa and tensile strengths from 270–700 MPa, while Ultra/Advanced High Strength Steels (UHSS or AHSS) steels have yield strengths greater than 550 MPa and tensile strengths greater than 700 MPa. In addition, many steel types have a wide range of grades covering two or more strength ranges. A third classification method presents various mechanical properties or forming parameters of different steels, such as total elongation, work hardening exponent n, or hole expansion ratio; all measures of formability as AHSS offer enhanced formability. As an example, Figure 1 compares total elongation – a property related to formability – for the different metallurgical types of steel (WorldAutoSteel, 2014).

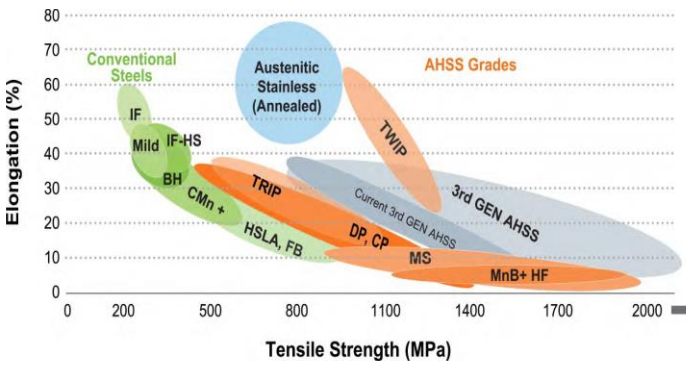

Figure 1. Global formability diagram, illustrating the range of properties available from today's AHSS grades (WorldAutoSteel, 2014).

The AHSS family includes Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS or MART), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). WorldAutoSteel, (2014**),** explained that the 1st and 2nd Generation AHSS grades are uniquely qualified to meet the functional performance demands of certain parts. For example, DP and TRIP steels are excellent in the crash zones of the car for their high energy absorption. For structural elements of the passenger compartment, extremely high-strength steels, such as Martensitic and boron-based Press Hardened Steels (PHS) result in improved safety performance (Keeler, 2002). Recently there has been increased funding and research for the development of the "3rd Generation" of AHSS. These are steels with improved strength-ductility combinations compared to present grades, with potential for more efficient joining capabilities, at lower costs. These grades will reflect unique alloys and microstructures to achieve the desired properties. The broad range of properties is best illustrated by the famous Global Formability diagram as shown in Figure 1 (WorldAutoSteel, 2014**)**. Although the seven steel types differ in the material composition, each features increased tensile strength and formability than in traditional steel products. These steels are known for their increased strength, lightweight composition, and improved performance under impact and energy transfer when exposed to a collision.

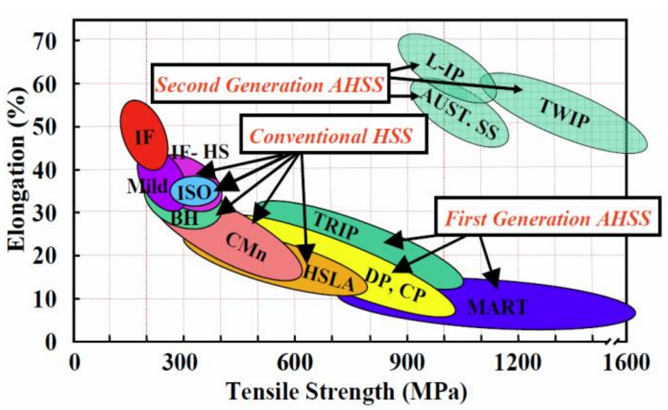

Figure 2. Relationship between tensile strength and total elongation (50.8mm gauge length) for various types of steel (r/t) for various AHSS (International Iron and Steel Institute, 2006)

The AHSS may be distinguished based upon the strength properties that roughly can be defined: yield strength > 300 MPa and tensile strength > 600 MPa. As opposed to the conventional high strength steels, in which ductility decreases with strength, modern AHSS steels combine high strength and formability/ductility. General classification of these steels is as follows according to International Iron and Steel Institute, 2006:

1. Highs strength steels with a high energy absorption potential (DP and TRIP steels with UTS < 1000 MPa), for dynamic loading occurring during car crashes or collisions. Extremely high strength steels, typically martensitic steels, with a very high UTS (>1200 MPa), providing high stiffness, anti-intrusion, load-transferring barriers for the protection of automotive passengers.
2. The rationales for increased use of the AHSS in the automotive industry are as follows:
3. The reduction of the car weight resulting from the use of high strength thinner gauge sheet steel, reducing the fuel consumption.
4. Increased passenger safety by an improved crash worthiness.
5. The strong competition from the light-weight materials, such as Al and Mg alloys and plastics.

There are several other variations of AHSS in use today, and they all rely on the same principles. Each manufacturer determines which formulation is used, based on specific engineering requirements (Robert, 2006). As automakers are challenged to improve safety and fuel economy, they search for new materials to meet higher standards. Advanced high-strength steels (AHSS) help engineers meet requirements for safety, efficiency, emissions, manufacturability, durability, and quality at a low cost. According to Alan (2006), AHSS are a newer generation of steel grades that provide extremely high-strength and other advantageous properties, while maintaining the high formability required for manufacturing. AHSS have been on the road for many years, but with additional research and development, automakers are using these newer grades in more applications. Stuart and Menachem, (2014) stated that While these steel types are relatively new, several automobile manufacturers have begun using up to 40% of AHSS in new vehicles. A primary challenge facing the collision repair industry is to identify correct repair policies and procedures for AHSS components.

According to Kuziak, et al, (2008), two major drivers for the use of newer steels in the automotive industry are fuel efficiency and increased safety performance. Fuel efficiency is mainly a function of weight of steel parts, which in turn, is controlled by gauge and design. Safety is determined by the energy absorbing capacity of the steel used to make the part. All of these factors are incentives for automakers to use Advanced High Strength Steels (AHSS) to replace the conventional steels used to manufacture structural parts in the past. AHSS is a general term used to describe various families of steels. The most common AHSS is the dual phase steel that consists of a ferrite-martensite microstructure. These steels are characterized by high strength, good ductility, low yield strength to tensile strength ratio and high bake-hardenability. Another class of AHSS is the multi-phase steel which has a complex microstructure consisting of various phase constituents and a high yield to tensile strength ratio (Kuziak, et al, (2008). Transformation Induced Plasticity (TRIP) steels is the latest class of AHSS steels finding interest among the automakers. These steels consist of a ferrite-bainite microstructure with significant amount of retained austenite phase and show the highest combination of strength and elongation, so far, among the AHSS in use. High level of energy absorbing capacity combined with a sustained level of high n value up to the limit of uniform elongation as well as high bake hardenability make these steels particularly attractive for safety critical parts and parts needing complex forming. In this paper, recent developments in the World in all these various classes of AHSS will be discussed. Finally, martensitic steels with very high strengths are also in use for certain parts (Matlock, et al, 2012, and Robert, 2006).

II. METHODS AND MATERIAL

2. Microstructure – mechanical properties characterization

2.1 Dual phase steels

DP steels consist of a ferritic matrix containing a hard martensitic second phase in the form of islands as observed in Figure 2.1. Curt, (2004), explained that, increasing the volume fraction of hard second phases generally increases the strength. DP (ferrite plus martensite) steels are produced by controlled cooling from the austenite phase (in hot-rolled products) or from the two-phase ferrite plus austenite phase (for continuously annealed cold-rolled and hot-dip coated products) to transform some austenite to ferrite before a rapid cooling transforms the remaining austenite to martensite (Stuart and Menachem, 2014). Due to the production process, small amount of other phases (Bainite and Retained Austenite) may be present.

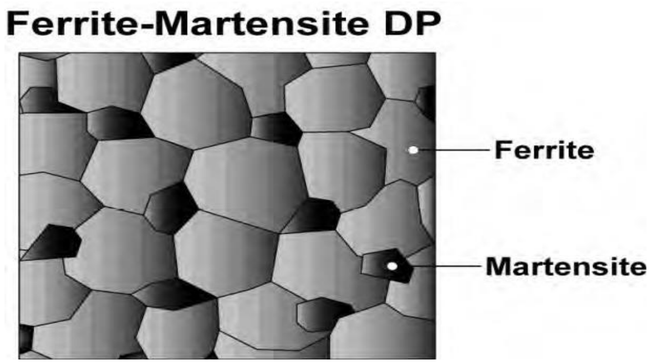

Figure 2.1: Schematic shows islands of martensite in a matrix of ferrite

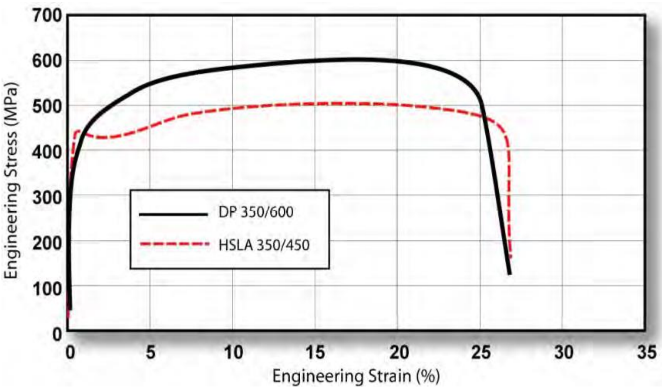

Figure 2.3. The DP 350/600 with higher TS than the HSLA 350/450K

Stuart and Menachem, (2014) explain that, depending on the composition and process route, steels requiring enhanced capability to resist cracking on a stretched edge (as typically measured by hole expansion capacity) can have a microstructure containing significant quantities of bainite. Figure 2.1 shows a schematic microstructure of DP steel, which contains ferrite plus islands of martensite. The soft ferrite phase is generally continuous, giving these steels excellent ductility. When these steels deform, strain is concentrated in the lower-strength ferrite phase surrounding the islands of martensite, creating the unique high initial work-hardening rate (n-value) exhibited by these steels. Figure 2.2 is an actual photomicrograph showing the ferrite and martensite constituents.

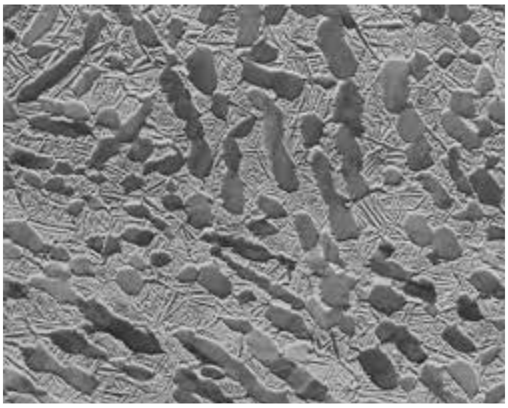

Figure 2.2. Photomicrograph of DP steel

The work hardening rate plus excellent elongation creates DP steels with much higher ultimate tensile strengths than conventional steels of similar yield strength. Figure 2.3 compares the engineering stress-strain curve for HSLA steel to a DP steel curve of similar yield strength. The DP steel exhibits higher initial work hardening rate, higher ultimate tensile strength, and higher TS/YS ratio than a similar yield strength HSLA.

2.2. TRIP Steels

TRIP stands for "Transformation induced plasticity." It is known for its outstanding combination of Strength and Ductility. Advanced high-strength transformation-induced plasticity (TRIP) steels are well suited for light-weighing car body construction with added advantage to reduce the safety problems. The steels rely on the transformation of austenite into martensite during deformation for achieving their mechanical properties and hence are known as transformation-induced plasticity (TRIP) steels. Robert, (2006), stated that there are two types of such steels. Those having a fully austenitic microstructure are called TRIP steels. These steels tend to be rich in nickel and other expensive austenite stabilising elements. By contrast, austenite is only a minor phase in the overall microstructures of TRIP-assisted steels (Matsumura et al., 1987a; Takechi et al., (1987). Allotriomorphic ferrite comprises about 50-60 vol.% of the microstructures of these materials, the remainder being a mixture of bainite and carbon-enriched retained austenite.

The mechanical properties of these steels are due to the transformation of retained austenite into martensite during deformation and hence appear to be dominated by the volume fraction and carbon content of retained austenite. These parameters have been related to the chemical composition and heat treatment of the steels with neural networks, using published data. Figures 2.4 and 2.5 showed the typical microstructures of TRIP steel and TRIP-assisted steel respectively.

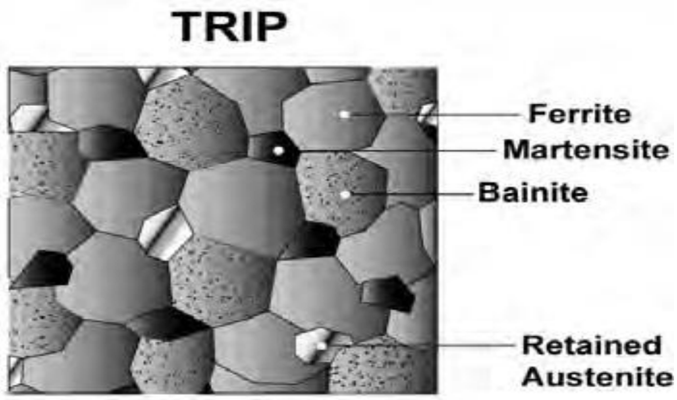

Figure 2.4 : Bainite and retained austenite are additional phases in TRIP steels

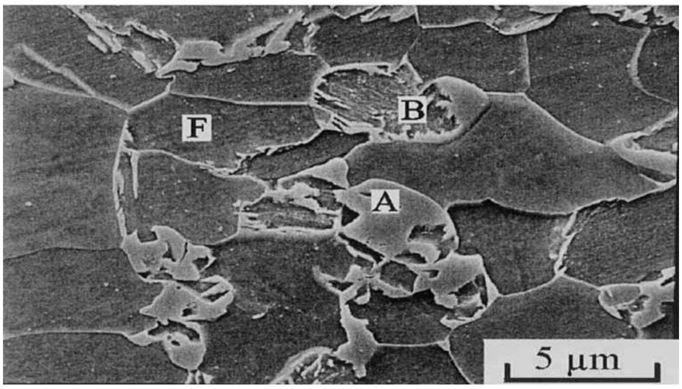

Figure 2.5 : A typical multiphase microstructure of a modern TRIP-assisted steel, with allotriomorphic ferrite (F), carbide-free bainite (B) and retained austenite (A).

2.3 Martensitic (MS) Steel

To create MS steels, the austenite that exists during hot-rolling or annealing is transformed almost entirely to martensite during quenching on the run-out table or in the cooling section of the continuous annealing line. The MS steels are characterized by a martensitic matrix containing small amounts of ferrite and/or bainite as observed in Figure 2-6. Within the group of multiphase steels, MS steels show the highest tensile strength level. This structure also can be developed with postforming heat treatment. MS steels provide the highest strengths, up to 1700 MPa ultimate tensile strength. MS steels are often subjected to post-quench tempering to improve ductility, and can provide adequate formability even at extremely high strengths. Engineering stress-strain curves for MS steel grades are located in Figure 2-7.

There are various types of MS grades currently used for automotive applications. Examples are MS 950/1200 used in the production of Cross-members, side intrusion beams, bumper beams, bumper Reinforcements while MS 1150/1400 used for the production of Rocker outer, side intrusion beams, bumper beams, bumper reinforcements.

Figure 2.6: Microstructure for MS 950/1200

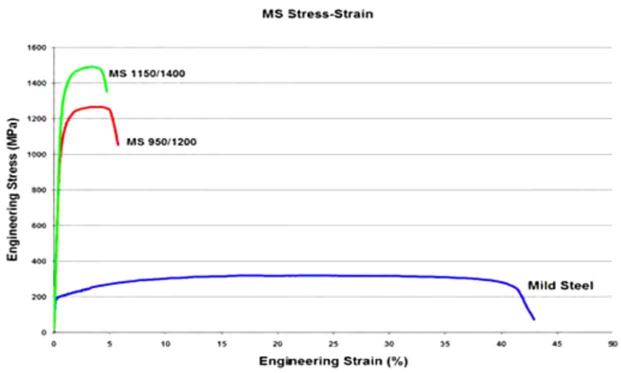

Figure 2.7 : Engineering stress/ strain curves for various type of MS steel grades

2.4 Complex Phase (CP) Steel

CP steels typify the transition to steel with very high ultimate tensile strengths. The microstructure of CP steels contains small amounts of martensite, retained austenite and pearlite within the ferrite/bainite matrix. An extreme grain refinement is created by retarded recrystallization or precipitation of microalloying elements like Ti or Nb. Figure 2-8 shows the grain structure for hot rolled CP 800/1000. In comparison to DP steels, CP steels show significantly higher yield strengths at equal tensile strengths of 800 MPa and greater. CP steels are characterized by high energy absorption, high residual deformation capacity and good hole expansion. Engineering stress-strain curves for CP steel grades are located in Figure 2-9. Current production grades of CP steels and example automotive applications are:

- CP 680/780 used in the production of Frame rails, chassis components, transverse beams, while CP 750/900 and CP 800/1000 are used for the production of B-pillar reinforcements, tunnel stiffener and Rear suspension brackets, fender beam respectively.

Figure 2.8 : Photomicrograph of CP 800/1000 hot rolled steel.

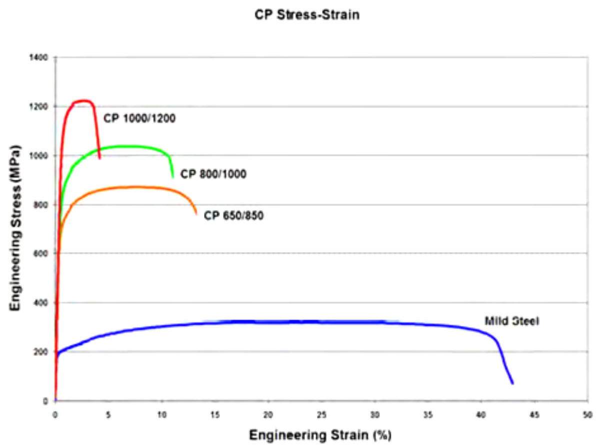

Figure 2.9 : Engineering stress-strain curves for a series of CP steel grades.V-1 Sheet thickness: CP650/850 = 1.5mm, CP 800/1000 = 0.8mm, CP 1000/1200 = 1.0mm, and Mild Steel = approx. 1.9mm (International Iron and Steel Institute, 2006).

3. Applications aspects of AHSS

AHSS, compared with conventional high strength steels of comparable strength give the automobile designer a high degree of flexibility to optimize the component geometry. Other component performance criteria comprise stiffness, durability, crash energy management. Jody, (2011), Carrie, (2011), and Curt, (2004), gave a short characterization of AHSS with respect to these criteria as follows:

a. Stiffness. The stiffness of a component is affected by material module of elasticity (E), as well as, its geometry. The module of elasticity is constant for steel, which means that changing steel grade does not affect the stiffness. Therefore, to improve stiffness, the component geometry must be changed. AHSS offer greater design flexibility to optimize the stiffness due to their enhanced formability. This can be done without increasing mass or decreasing strength. Reduction in gauge can be counterbalanced by changes in geometry or by using continuous joining techniques such as laser welding or adhesive bonding.

b. Strength. Strength of a component depends on its geometry and yield and/or tensile strength. AHSS provide an advantage in the design flexibility over conventional high strength steels due to their higher formability and work hardening characteristics. These grades also have good bake hardening ability. Therefore, it is important to account for this strength increase during the design process of car components in order to avoid the over design that may occurs when the design process is based upon as rolled mechanical properties specification. Both these features enable achieving high strength of as-manufactured components.

c. Fatigue. Fatigue properties of structural components depend on geometry, thickness, applied loads and material endurance limit. The endurance limit of a material increases with tensile strength. Thus, high strength combined with superior work hardening and bake hardening, resulting in a significant increase in the as-manufactured strength of AHSS components, also results in a better fatigue resistance.

d. Crashworthiness. Crashworthiness is an important characteristics that is currently becoming increasingly important. Recent trends require for a material to absorb more energy in crash scenario. The potential absorption energy can be assessed based upon the area under the stress-strain curves. Better performance in crash of AHSS compared to classical high strength steels is associated with higher work hardening rate and high flow stress. This feature account for a more uniform strain distribution in components in the crash event. Both, work hardening and bake hardening significantly improve the energy absorption characteristics due to the flow stress increase.

e. Formability. AHSS have many advantageous characteristics connected to formability compared to those of HSLA steels with comparable yield strength. AHSS in general have a higher initial work hardening rate, their higher ultimate tensile strength and, especially DP steels, have lower ratio of yield strength to tensile strength. All these advantages combined with an excellent elongation show, that AHSS combine high strength with good formability. High work hardening exponent accounts for the ability of a sheet metal to stretch and the ability of steel to distribute the strain more uniformly in the presence of a stress gradient.

III. CONCLUSION

The family of AHSS continues to grow and evolve. Many grades of AHSS have been developed to meet the unique and varied performance requirements of the many components of the vehicle. Each type may be tailored to have a specific set of characteristics from a broad range of possibilities. These steels, while improving the strength and safety of cars on the road today, also offer flexibility for automotive engineers who seek to design novel, light-weight solutions. Increasingly selected for application in vehicles to address challenges faced by automakers, AHSS can help improve safety, fuel efficiency, manufacturability, durability, and quality, while minimizing the lifetime greenhouse gas emissions from production, use, and end-of-life phases of the vehicle. AHSS also remain an economical choice in the highly competitive automotive industry. AHSS have a bright future in automotive structural applications and are poised to revolutionize how steel is used to manage structural crash energy. The single greatest impact of AHSS's will come from integrating these materials with efficient structural designs and efficient joints. AHSS's represent the greatest opportunity to maintain steel as the primary body structure material and to provide our customers with a low cost and exceptionally safe vehicle.

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