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ADVANCED STEEL PRODUCTS FOR LIGHTWEIGHTING AT DAIMLERCHRYSLER

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Abstract

Ever since the oil shortage of the 1970s and the introduction of tougher environmental regulations, the automotive community has been challenged to push initiatives leading to higher vehicle fuel efficiency. Initial efforts worked to downsize vehicles, while at the same time substituting the traditional body-on-frame, rear-wheel drive architecture, with the lower mass unibody, front wheel drive architecture. Lighter vehicles with smaller and more efficient powertrains have led to significant improvement in fuel economy. Since then, customer driven requirements for more personalized driving characteristics such as increased cockpit comfort, accessories, enhanced performance, functionality, and safety have allied with relatively affordable fuel prices to once again lead the North American industry to steadily increase vehicle size, powertrain displacement and a return to rear wheel drive architecture, while still meeting stringent fuel economy requirements. This paper will cover the current automotive trends towards advanced materials utilization for the body-in-white at DaimlerChrysler in order to meet the requirements of light-weighting while maintaining or increasing overall vehicle safety.

Introduction

Requirements for the body-in-white (BIW) include high energy absorption, low weight, passenger-cabin intrusion resistance, enhanced stiffness, corrosion resistance, and reduced cost [1]. Traditional high volume unibody assemblies call for significant investment in large forming presses, fixtures and tooling to locate and secure parts, and spot welding robots. The essential virtues of unibodies are low production costs and high stiffness to weight ratios obtained by distributing stresses more evenly in all directions, much like an egg shell (SAE 2002-01-2091). While unibodies show excellent stiffness-to-weight ratios, they are not as efficient when impacted with a significant component perpendicular to the shell. Therefore, current designs aim at an extremely stiff and strong compartment, also called the "safety cell", protected by softer structures designed to absorb energy while deforming in a crash. The basic concept for improved crash performance is to have an undeformed safety cell with minimum deceleration of the vehicle occupants upon impact [1].

Since the BIW constitutes 25 to 30% of the total vehicle weight while only accounting for 10 to 15% of the total cost, light weighting of this structure is often one of the most cost effective solutions to reducing the overall vehicle weight. After changing architecture and overall vehicle size during the oil crisis of the late 1970's, the automotive industry's approach to meet the increasingly stringent requirements for light weighting was to intensify the use of low density materials.

The increased material and processing costs associated with low-density metals, for high volume production, have proved to be unacceptable and have led to the pursuit of alternative light weighting solutions. The steel industry's response to lightweighting and the increasing use of lower density materials has been to develop higher strength steels with favorable ductility. These sheet steels (commonly referred to as advanced high strength steels or AHSS) combine soft and hard phases resulting in favorable strength-to-ductility ratios [2]. This combination of improved strength and ductility makes it possible to simultaneously improve the strength and reduce the vehicle weight through reduction in sheet thickness. Reduction in stiffness associated with thinner gauges can usually be overcome by using continuous joining techniques, such as adhesive bonding or laser welding, and/or by geometry changes. AHSSs such as dual phase, complex phase, and retained austenite (commonly known as Transformation Induced Plasticity or TRIP) steels have high tensile strengths, low yield-to-tensile ratios, bake hardenability and improved ductility compared to materials with similar tensile strengths [3, 4]. AHSSs can also be processed with the existing automotive manufacturing infrastructure.

Steel's high Young's Modulus, formability, weldability, range of properties, ability to be coated for corrosion protection, recyclability, and low cost, makes it the current material of choice for large volume unibody construction processed with conventional manufacturing methods. Sheet steel will therefore be the main focus of this review.

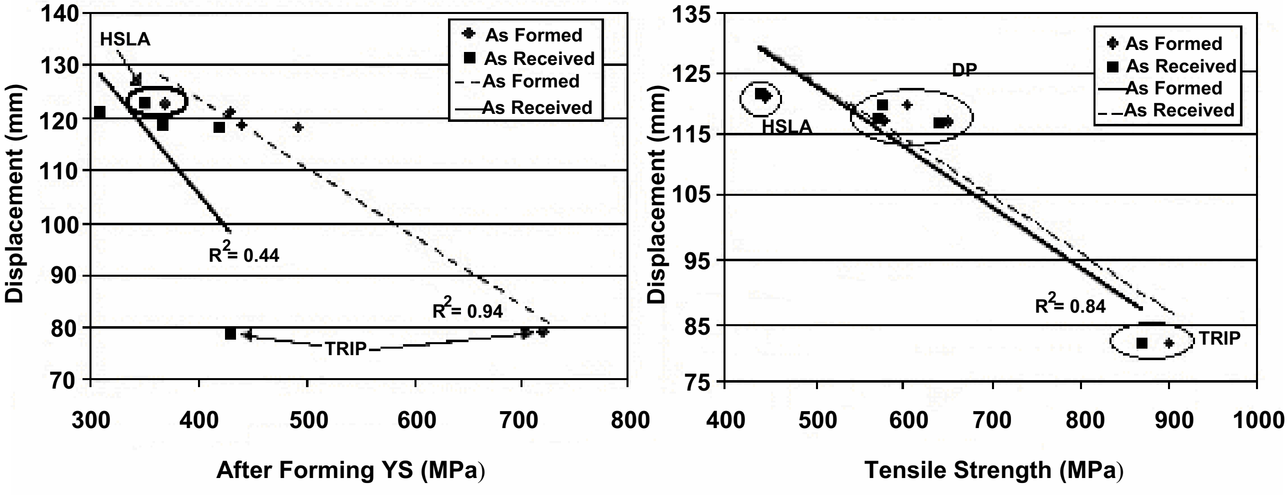
Crash Energy Management

The crash energy management requirements for automobiles have been reviewed previously [5]. For thin wall rectangular columns, such as front and rear rails, the dynamic behavior of deformation in a stable axial collapse is frequently described by equations of the form [6]:

$$P_m = K\sigma t^a \tag{1}$$

P_m = Average load (or absorbed energy),
K = constant related to geometry,
σ = Flow Stress term,
t = Thickness, and
a = Thickness exponent

The amount of absorbed impact energy has been empirically estimated assuming it is proportional to the product of the 0.5th power of the tensile strength ($\sigma = (\sigma_{uts})^{0.5}$) and the 2nd power to plate thickness ($a = 2$) [6]. There is a strong relationship between tensile strength and the energy absorbed during crushing of square-hat columns [7, 8, 9]. Fekete et.al. have illustrated with HSLA 340 MPa minimum yield strength, Dual Phase 600 MPa minimum tensile strength, and TRIP 780 MPa minimum tensile strength grades that the amount of energy absorbed in a drop weight type test of hat-like sections showed good correlation with the material's tensile strength, but closer correlation with the as-formed yield strength [10]. Incoming yield strength (quasi-static) shows poor correlation with energy absorption. Figure 1 shows the relationship between sheet steel's yield/tensile strength and energy absorption. Internal work conducted at DaimlerChrysler has shown good correlation between the average yield and tensile strength during dynamic tensile tests and uni-axial crush. Many empirical relationships between tensile properties and energy absorption during uniaxial crush exist, but the automotive industry has recognized the need for accurate high strain rate data and the incorporation of the forming strains for precise finite element modeling of crash events. The low yield-to-tensile strength ratios and high work hardening rates associated with advanced high strength steels, promotes higher energy absorption during stable axial collapse when compared to conventional steels of similar yield strength [7, 9, 11, 12].



(a) **(b)**

Figure 1. Correlation of drop-weight tower slide displacement to yield (a) and tensile strengths (b).

There is still much debate amongst the automotive community as to which material is best suited for crash applications. Due to its metastable microstructure and consequent forming ability, the automotive industry is showing special interest towards TRIP steels. The challenges and unknowns associated with processing and mechanical properties, as well as limited availability in North America, are currently inhibiting their use [13-16].

As an example of future advanced high strength steel applications at DaimlerChrysler North America, Figure 2 shows a body-in-white for a 2005 model Chrysler 300 sedan. High strength steels are used extensively for the body-in-white with advanced high strength steel (dual phase 600 MPa minimum tensile strength) used for the front rails providing improved energy absorbing characteristics when compared to 340 MPa high strength low alloy (HSLA) steels. Weight savings associated with the use of dual phase steels for the front end are in excess of 12%. The new model's body-in-white has a 21% increase in high strength low alloy sheet steel and is the first vehicle at DaimlerChrysler North America to rely on Dual Phase 600 for the entire front rail system. Other rear wheel drive vehicles including the Dodge Magnum and Charger also employ DP600 for the front rail system. Not shown are the ultra high strength steel reinforcements such as door beams and bumper reinforcements. The Chrysler Pacifica also relies on DP 600 steel to achieve its 5-star crash rating, especially in the front offset crash test, while at the same time reducing 2.11 kg from a compression plate application.

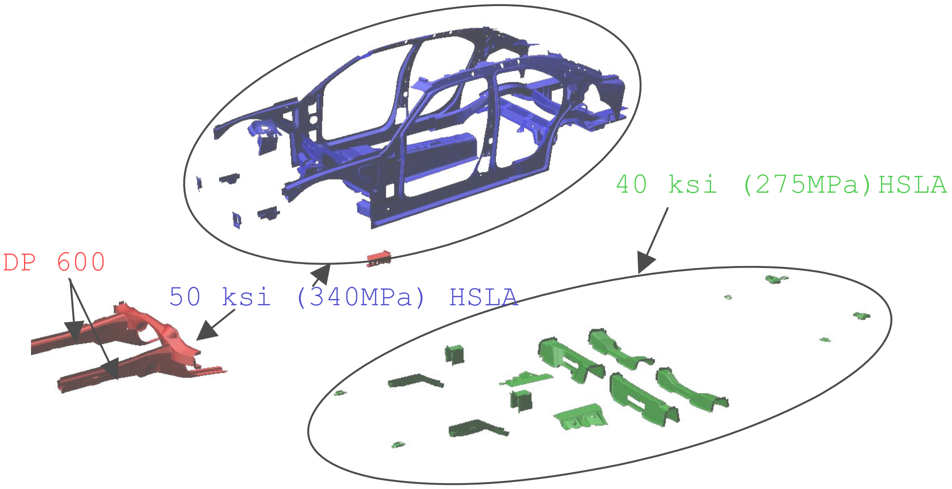


Figure 2. Utilization of high and advanced high strength steels for a 2005 Chrysler 300 sedan.

Engineers at DaimlerChrysler have identified the use of higher strength steels as a cost-effective solution for the new challenges of improved crash resistance and reduced vehicle body weight. Figure 3 shows the extensive use of DP600 on the 2005 Jeep Grand Cherokee throughout the body. While low carbon (mild) steel represents over 60% of the body-in-white weight for current vehicles, the next generation vehicles have significant high and ultra high strength steel utilization targets. Figure 4 shows the steel usage for next generation C-segment vehicle from the Chrysler group. Over 50% of the body-in-white employs high strength steels with significant percentage of advanced high strength and ultra high strength steels.

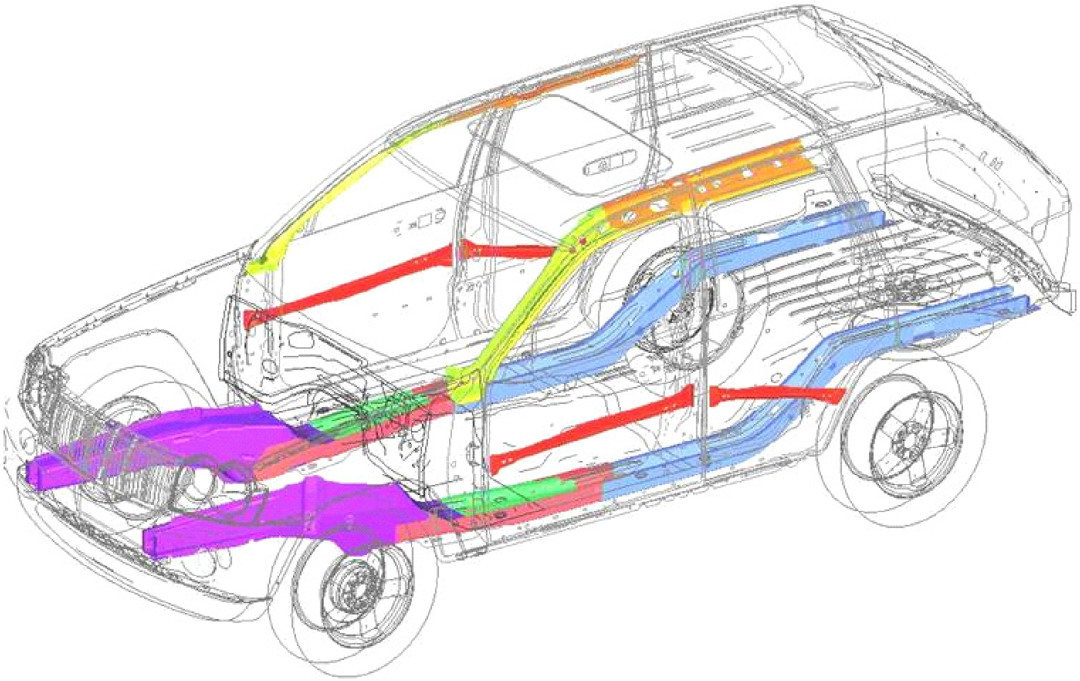
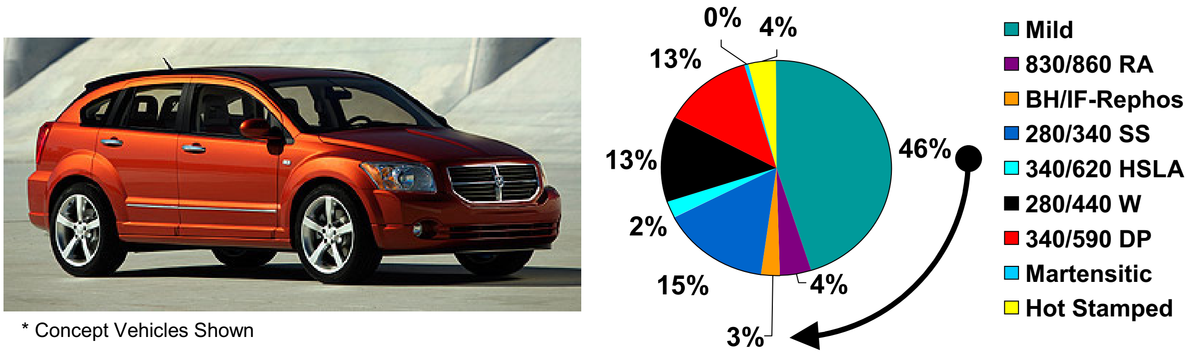


Figure 3. DP600 usage for the 2005 Jeep Grand Cherokee.



* Concept Vehicles Shown

Figure 4. Steel utilization for a 2006 DaimlerChrysler C-Segment vehicle.

Intrusion and Rollover Protection

Intrusion and rollover protection are two key functions of the “safety cell” [5]. During side impact, transversely loaded components, such as rockers, pillars, door beams, and roof rails require high resistance to plastic bending, as well as high stability and rigidity for superior performance [6, 17]. These requirements are achieved by the use of a crash optimized cross sectional shape and ultra high strength steels, with a focus on high yield strength. Several types of high strength materials with various strengthening mechanisms are currently employed, with different material properties and processing requirements. One processing alternative for achieving high yield strengths is to “dissociate” the properties required for forming and those necessary in service. Hot stamping is a process where the blank is heated and transported into the forming tool (Figure 5). Forming and hardening take place in one step while tempering can be executed as a separate operation or brought about by the parts own heat in the press. Tensile strengths of over 1300 MPa and elongations of over 8% can be achieved. Since the component remains locked in the tools during the hardening process, distortion is kept to a minimum. Figure 6 shows a few of the hot stamped components for next generation C-segment vehicle safety cage from the Chrysler group. Both uncoated and coated components are employed while a tailor rolled B-pillar results in significant weight savings and crash performance. Similar properties can be achieved by cold forming followed by separate heating, quenching and tempering operations, but distortion during heat treatment typically becomes more of an issue.

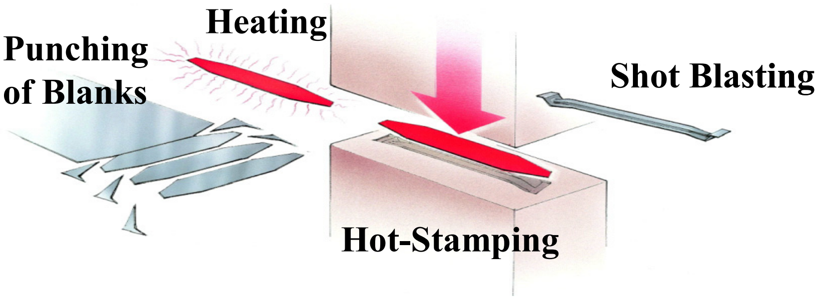


Figure 5. Hot stamping process (Courtesy of SSAB Hardtech).

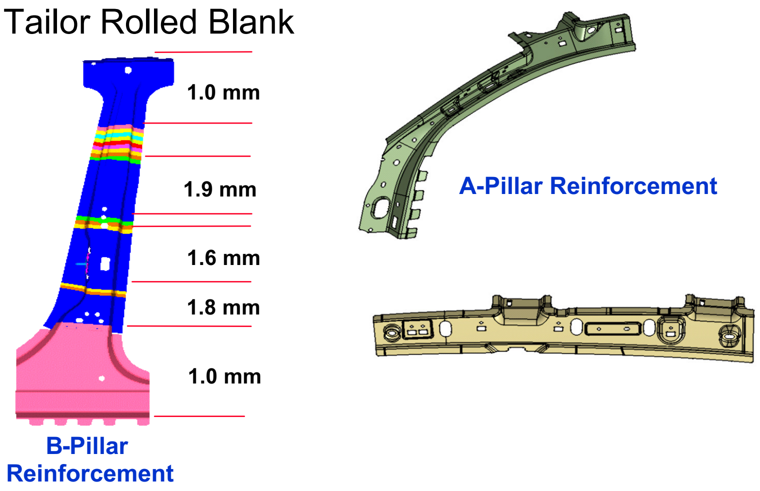


Figure 6. Hot stamping applications used in the C-segment safety cage.

Roll forming is another forming process that enables the use of materials with tensile strengths in excess of 1000 MPa to form profiles that would otherwise be difficult due to limited ductility. This approach has widespread usage in North America, but the low ductility of these materials after roll forming limits their use to anti-intrusion components. Roll formed sections and hot stampings are the main processes at DaimlerChrysler for bumper systems, which are then bolted onto the body-in-white. The future trend for bumpers will be to integrate the bumper system with energy absorbing front and rear-end structures while providing a high degree of commonalty for component sharing among different platforms. This design enables improved impact performance, flexible manufacturing, and low cost.

The increased processing costs associated with hot forming, and the geometric limitations of roll forming have further pushed the steel industry to develop advanced high strength steels capable of cold forming into more complex shapes. Rapid development of dual phase, complex phase, and TRIP steels allow existing forming methods to be used, thereby avoiding the additional processing and investment costs associated with alternative forming methods [18]. This approach does not come without its own challenges. Currently, the ability to form to precise dimensions and join these materials is extensively researched in the automotive community.

At DaimlerChrysler North America, both hot stamping and cold-formed anti-intrusion solutions can be found, with hot-stampings door beams found in several vehicle programs. Figure 7 shows some of the structural members for the body side and header for the new Dodge Durango. The new Durango uses a tailor welded blank body side inner with a thicker gauge rear section for added stiffness. A high strength front door ring and dual phase 600 front header contribute to improved side impact and rollover protection. In addition, high strength steel sills and pillar reinforcements are employed. Figures 8 a, b, and c are examples of door beams used at DaimlerChrysler for an SUV, car, and truck, respectively. Door beam type and manufacturing technique vary, but the main characteristics for all the beams are high yield strength, good weldability, and material toughness.

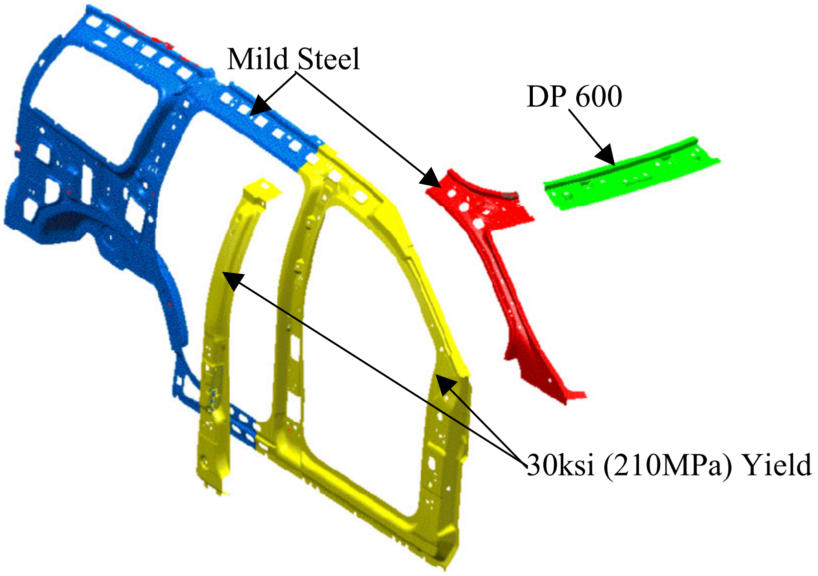
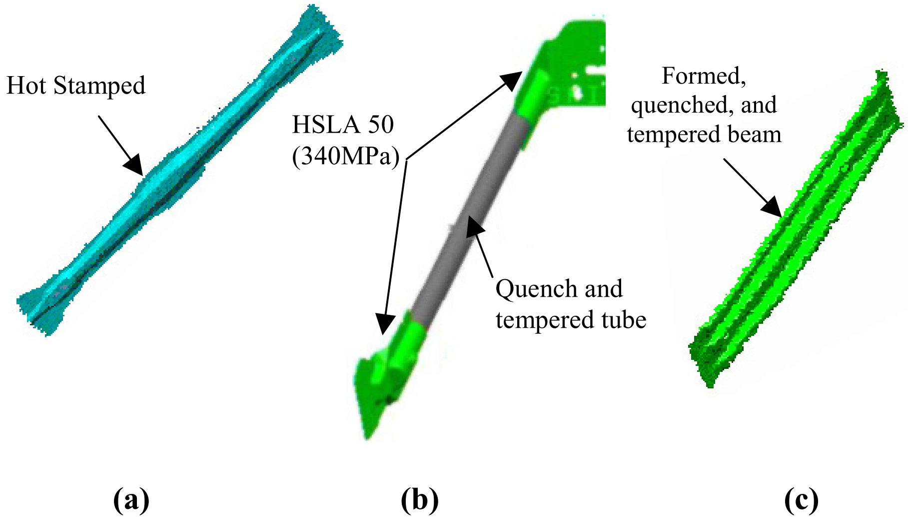


Figure 7 - New Dodge Durango body side inner, header, and reinforcements.



(a) **(b)** **(c)**

Figure 8 – DaimlerChrysler SUV (a), car (b), and truck (c) door beams.

Stiffness and Noise-Vibration-Harshness (NVH)

The primary factors controlling the static bending and torsion performance of the automobile body structure are section geometry, elastic modulus, and gauge [6]. DaimlerChrysler has investigated applications where weight reduction is possible while maintaining stiffness or other product requirements. Structural Steel-Composite-Steel (SCS) sheet material, a laminated structure with thin steel sheets on the outside encompassing a thick polymer layer in the center, increases section gauge while limiting the weight increase of a similar gauge homogenous material (Figure 9). Since SCS cannot be resistance spot welded, the applications are limited to riveted, bolted, and/or adhesive bonded applications. The greatest advantage of the SCS material over conventional steels is the added stiffness associated with the total section gauge without the added weight. Since the composite material accounts for a large portion of the sheet's cross-section, the stiffness increases without having to sacrifice increased weight. This configuration is possible because in bending the outer layers of a sheet material carry the majority of the load, while the polymer (close to the neutral axis) remains unstressed [19]. Figure 10 shows that the

SCS laminates have approximately equal bending stiffness as monolithic sheet steels of equivalent total thickness.

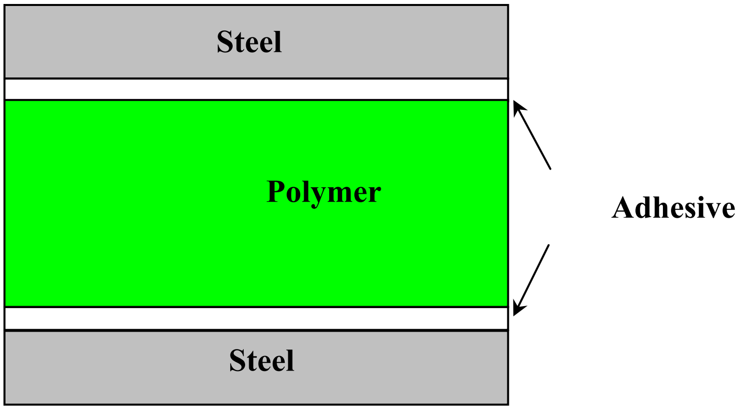


Figure 9. Example of a Structural Steel-Composite-Steel (SCS) sheet.

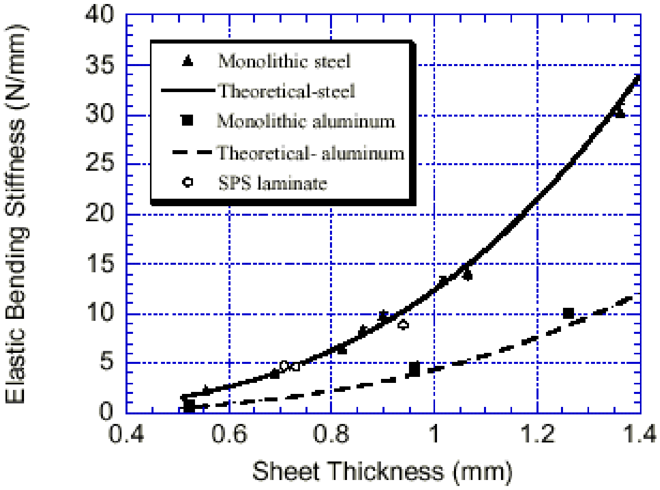
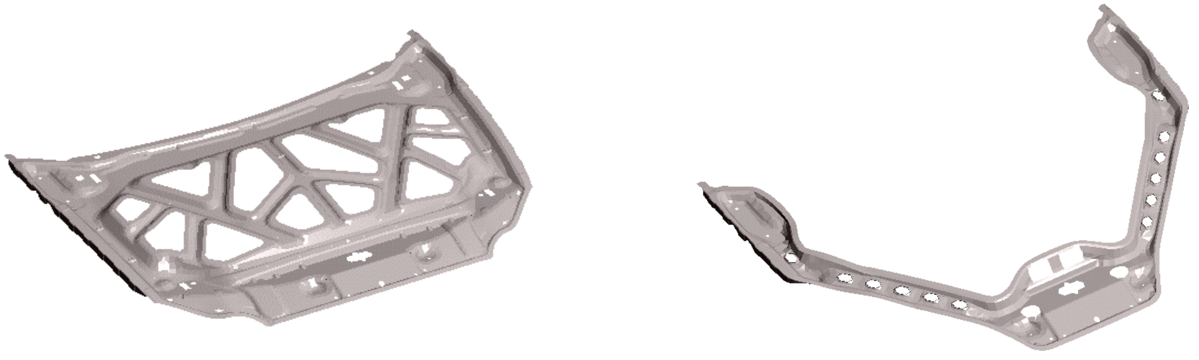


Figure 10. Elastic bending stiffness as a function of total sheet thickness for SCS laminates, monolithic steels, and monolithic aluminum alloys [18].

Weight savings through the use of composite sheets have been realized by the possibility of combining two factors [19]:

1. Reduction in the weight per unit area of the part, while maintaining an equal or greater stiffness;
2. Functional redesign based on a very stiff composite sheet, enabling the elimination of reinforcements and liners.

Based on the second assumption, a hood optimization program was carried out by DaimlerChrysler in partnership with UsinorAuto. By utilizing DaimlerChrysler North America's Static Hood Evaluations Laboratory Procedure as the baseline, finite element analysis of steel, aluminum, and a SCS hood were conducted. The basic geometry of the hood remained unchanged for the three materials, while the steel hood inner was optimized to take advantage of the added stiffness of the SCS outer skin. Figure 11 shows the current hood inner design, compared to the optimized inner enabled by the use of a SCS hood outer. Both inners where made of steel.



Current Steel Hood inner Alternative Steel Hood inner

Figure 11. Hood inner designs.

The total weight savings, considering both inner and outer panels, are summarized in Table I. Although the total weight savings associated with the SCS hood is slightly lower than that associated with the aluminum hood, the price penalty is expected to be on the order of 1/3 that of the aluminum hood assembly.

Table I. Weight Savings for Aluminum and SCS hoods in comparison to a baseline steel hood.

	Hood Outer Material		
	Steel	Aluminum	SCS
Weight Savings (%)	Baseline	48%	40%

Laminate materials can also be used for sound deadening applications where the weight (and cost) savings usually arise from the elimination of sound deadening layers such as mastics or robotically applied spray dampers. Sound deadening laminates are different than structural laminates because the material "sandwiched" between the two steel sheets is a very thin layer of a visco-elastic resin, which absorbs vibration and reduces the resonant frequency of the laminate. The vibration energy generated is converted into heat, which is then dissipated within the structure. Sound deadening laminates can be formed and welded much like a conventional steel sheet [20]. While early applications were limited to engine and powertrain components, applications such as dash panels, wheel houses, spare tire tubs, and upper cowls are now being employed [21]. Several current, such as the Jeep Commander, and upcoming Chrysler group vehicle will employ sound deadening laminates for improved NVH performance.

Dentability

Significant research in exposed quality sheet steel has led to the development of higher yield strengths for potential down gauging and improved dentability resistance. While bake hardenable (BH) and Interstitial Free Rephosphorized (IF-RePhos) steels are currently the focus of dentability issues, DaimlerChrysler and steel producers have recognized the connection between increasing yield strength and improved dentability resistance and are employing even higher yield strength sheet steels for exposed applications. DaimlerChrysler in cooperation with ThyssenKrupp Steel has conducted trials using dual phase (DP) 500 MPa (300 MPa yield strength) steel for door outer panels for a current production light duty sport utility vehicle. Figure 12 shows test data for dent force versus dent depth of the DP 500 (tensile strength) at 0.70mm gauge compared with a BH 180 (MPa yield strength) at 0.75mm gauge. Depending on test location, the applied load required to produce a given dent depth is as much as 100N higher for the DP 500. The forming characteristics of the dual phase steel were analyzed and soft tool changes to the production tool design were made to produce a dual phase door outer panel of equivalent quality and aesthetics as the current production door. Optimization of the panel gauge using DP 500 steel led to a 24% weight reduction and 11% cost reduction from the current production doors. Based on the trials, future DaimlerChrysler product are likely to employ the use of higher strength sheet steels to reduce weight and improve performance of exposed panels. However, processing and material issues associated with stretch flanging, bending, and hemming must be overcome to prevent limiting body design and processing.

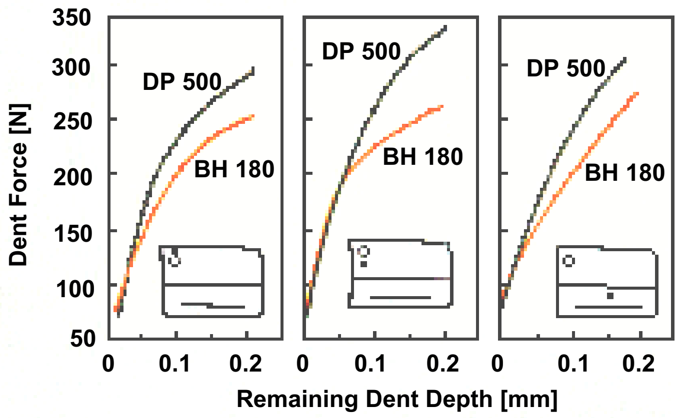


Figure 12. Relationship between dent force and dent depth at various locations for DP 500 and 180 BH door outer panels.

Conclusion

This paper has reviewed general industry-wide trends in the utilization of steel for body-in-white and closure applications, with focus on current usage at DaimlerChrysler North American Group. Steel is shown to be a strong contender for mass production type operations due to its high elastic modulus, ease of processing, recyclability, and properties associated with the different steel grades. New steel grades with increasingly attractive properties such as high work hardening rates, increased strength-to-ductility ratios, and bake hardenability, have expanded the already broad range of steel products for various automotive applications for steel products. These developments continue to demonstrate the steel industry's capability of providing engineered solutions for weight reduction and vehicle performance improvement while utilizing the existing automotive manufacturing infrastructure.

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