Three generations of advanced high-strength steels for automotive applications, Part I

The first generation

BY EREN BILLUR AND TAYLAN ALTAN

Editor's Note: This article is Part I of a three-part series summarizing the three generations of advanced high-strength steels (AHSS) used in automotive applications. Parts II and III, which will appear in the January/February and March/April 2014 issues, respectively, will discuss second- and third-generation AHSS.

The most common classification of steels is by metallurgical differences. As seen in **Figure 1**, steels can be classified as mild steel, conventional high-strength steel (HSS), and advanced high-strength steel (AHSS). The latter has three generations.

Increasing safety and fuel economy regulations have been pressuring the automotive industry to design safer yet lighter vehicles. HSS and AHSS have been replacing mild steels for the last decade in automobile bodies. The typical, recently introduced vehicle contains about 30 percent HSS and 30 percent AHSS.

Mild Steels

Mild steels generally comprise one microstructure: ferrite. These steels have a maximum tensile strength of 280 MPa (40,000 PSI) and are very easy to form. Mild steels were once the dominating material in car bodies, but now their use is limited to stiffness-related components and cosmetic parts with complex bending and drawing.

The two main material types in this group are:

1. Mild steels (also called low-carbon or plain carbon steels), which have very little alloying element.
2. Interstitial-free (IF) steels, which have ultralow carbon and even lower strength, but higher formability.

High-strength Steels

The main strengthening mechanism in conventional HSS is solid-solution hardening. In the **bake-hardenable (BH) steels**, the chemistry and processing are designed to take carbon out of solution during the paint baking cycle. In this way, the steel is made softer and more formable for the press shop, but it gains more strength after being put in service.

Carbon-manganese (CMn) steels are mild steel solid solution, strengthened by adding manganese alloy. **High-strength, low-alloy (HSLA) steels** are CMn steels strengthened with the addition of a microalloying amount of titanium, vanadium, or niobium. These steels, with a tensile strength up to 800 MPa (115,000 PSI), still can be press formed (see **Figure 2**).

HSLA was one of the first commonly used HSS in the automotive industry in the 1990s. These steels are still used in many cars—BH steels in body closures, CMn and HSLA in energy-absorbing areas. However, AHSS is replacing HSLA in these applications, since it can absorb more energy.

Advanced High-strength Steels—The First Generation

First-generation AHSS have more formability than HSLA at the same strength level. These steels typically have a martensitic microstructure, sometimes with one or more additional phases to improve formability. Martensite is the hardest and strongest form of steel, but it also is the

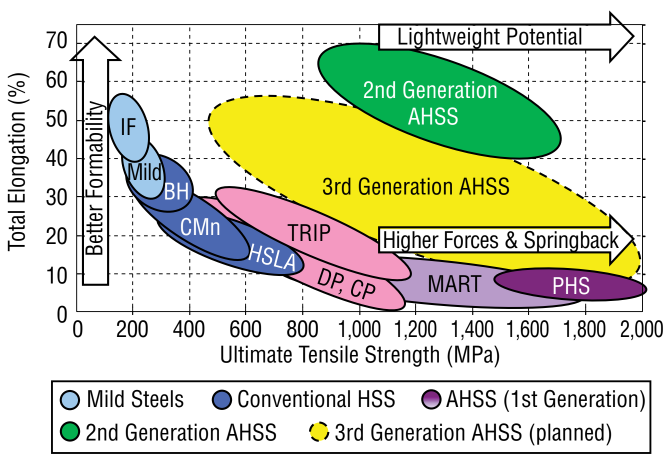

Figure 1

Steels can be classified as mild steel, conventional high-strength steel (HSS), and advanced high-strength steel (AHSS). The latter has three generations.

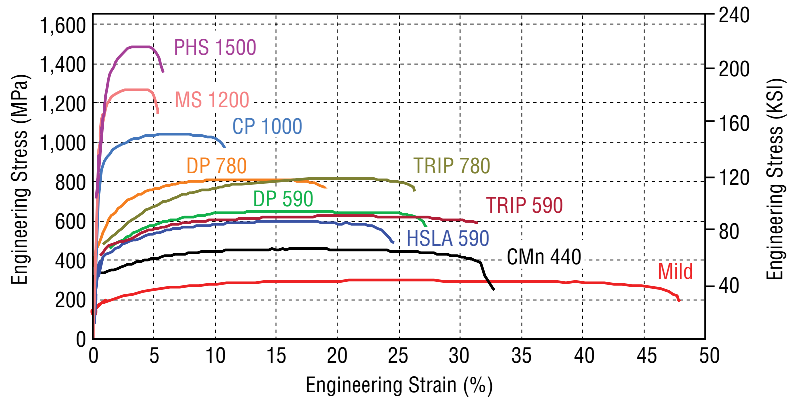

Figure 2

Strength (engineering stress) and formability (engineering strain) vary greatly among the various types of steel.

least formable. To make strong steels formable, a mixture of formable and strong phases is required.

The most commonly used AHSS today is **dual-phase (DP) steel**, which contains ferritic and martensitic phases for a balance between formability and strength. DP steels typically have higher elongation than HSLA at similar strength levels. This unique microstructure is created by special heat treatments. Currently DP steels are available with tensile strengths from 590 to 1,400 MPa (85 to 200 KSI). DP steels are used in applications such as crashboxes, front end structures, A and B pillars, roof rails, and sill reinforcements.

Complex-phase (CP) steels usually have higher formability than DP and contain bainite in addition to martensite and ferrite. Grain refinement is created by adding titanium, vanadium, or niobium microalloys. These steels have strength levels of 800 to 1,180 MPa (115 to 170 KSI) and commonly are used in car bodies in Europe. Typical applications include sill reinforcements and A- and B-pillar reinforcements.

Transformation-induced plasticity (TRIP) steels contain retained austenite in addition to ferrite and martensite. When these steels are deformed, the austenite transforms to martensite, which helps distribute the strain and increase elongation. These steels have higher formability than CP, DP, and HSLA. TRIP steels currently are available in tensile strengths from 590 to 1,180 MPa (85 to 170 KSI). TRIP is replacing DP and HSLA steels because of its higher energy absorption and its ability to be formed into complex components with deep draws. Typical applications include cross members and front and rear rails.

Martensitic steels (MS) are, as the name suggests, mostly martensitic with some small amounts of ferrite and bainite. These steels have the highest strength but lowest elongation (or formability) levels. Martensitic steels, currently available with strengths of 900 to 1,700 MPa (130 to 245 KSI), are used in automobile body parts in which deformation may be limited.

Martensitic steels are very hard to press form, so they typically are roll formed or press hardened (hot stamped). In press hardening, the manganese-boron-alloyed steels are heated, formed, and then quenched to get their final strength. Springback is eliminated, and very strong components can be formed to complex geometries.

Typical **press-hardened steels (PHS)** (or hot stamped) have tensile strength of 1,500 to 1,800 MPa (215 to 260 KSI). In the last decade, they have been used extensively in safety and crash-resistant car body components. New-generation PHS are expected to have strength of 2,000 MPa (290 KSI). Both of these PHS grades are used where only very small deformation is allowed. These steels have been adopted for use in many parts, including sill structure, as well as A- and B-pillar reinforcements, in recent cars. Recently many floor panels also are being hot stamped to save weight.

One of the major issues facing the OEMs and suppliers that use AHSS is edge cracking during flanging at room temperature or under crash conditions. Thus, the condition of blanked and sheared edges of blanks, including the amount of strain hardening and burr formation at the blanked edge, is extremely critical for subsequent deformation of the part in stamping and during a crash.

Resources

"AHSS Applications Guidelines, V4.1," WorldAutoSteel, Middletown, Ohio, June 2009.

Automotive Steel Data Book, *POSCO, Pohang, South Korea, 2012.*

Dykeman, J., "Advanced High Strength Steel - Recent Progress, Ongoing Challenges, and Future Opportunities," presented at AIST Symposium, Vail, Colo., June 2013.

Proceedings of EuroCarBody, sponsored by Automotive Circle Intl., Bad Nauheim, Germany, Oct. 2011 and Oct. 2012.

Tamarelli, C.M., "AHSS 101 – The Evolving Use of AHSS for Automotive Applications," Steel Market Development Institute, Washington, D.C., 2012.

Eren Billur is a postdoctoral researcher and Taylan Altan is professor and director of the Center for Precision Forming (CPF) at The Ohio State University, 339 Baker Systems, 1971 Neil Ave., Columbus, OH 43210, 614-292-5063, www.cpforming.org and www.ercnsm.org.