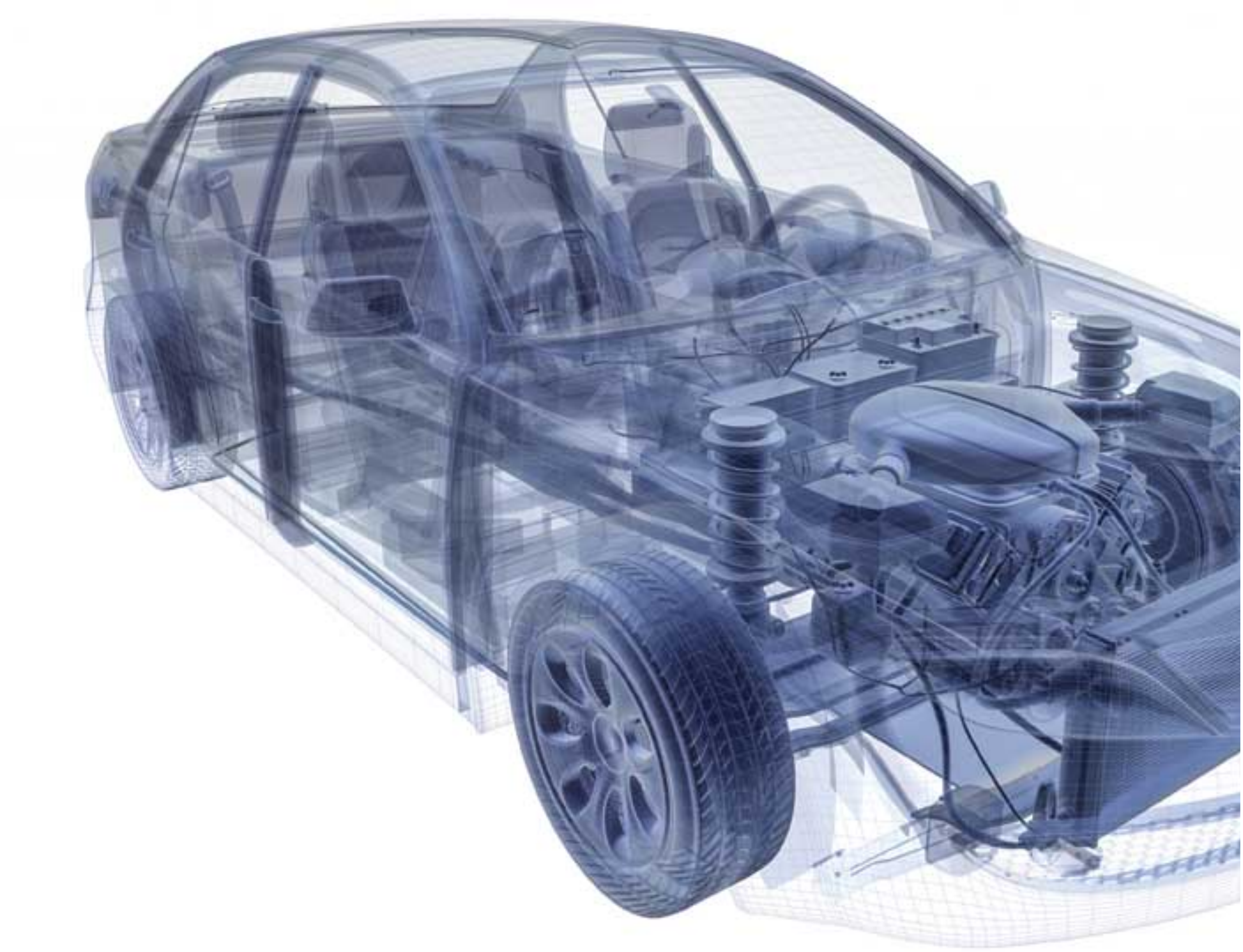
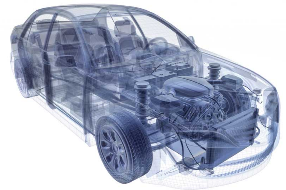
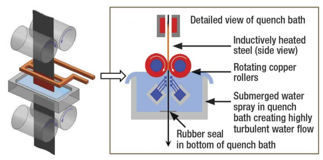
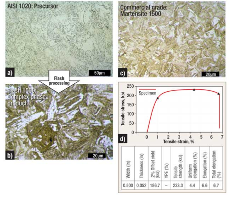
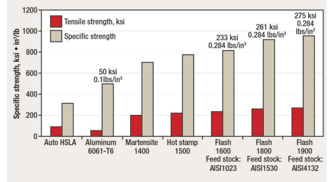
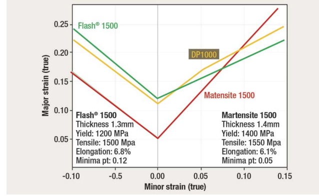
INDUSTRIAL HEATING

Induction Heat Treating

Flash® Processing for High-Strength, Cold-Stampable Automotive Steel




Flash® processing of common steel is a promising manufacturing technology that can be used to produce high-strength, cold-stampable automotive steel for safer, lighter and more fuel-efficient vehicles.

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U.S. automakers will need to develop and commercialize a number of new vehicle technologies in order to meet the Corporate Average Fuel Economy (CAFE) standards for light-duty vehicle fleets. To help the industry meet this challenge, the Department of Energy (DOE) is partnering with industry stakeholders to support the development of materials for vehicle lightweighting. A number of studies have indicated that reducing vehicle weight by 10% could increase fuel efficiency by 6-8%.[1]

R&D lightweighting efforts are focusing on replacing heavy steel components with the most promising materials, including advanced high-strength steels (AHSS), aluminum alloys, magnesium alloys and fiber-reinforced composites. The last three materials tend to be more expensive than the steels they would replace, however, and also require some level of factory retooling.

AHSS needs to provide a combination of extremely high-strength, good cold formability and low cost to offer the potential of structural components at reduced weight while also maintaining compatibility with the existing manufacturing infrastructure. Pathways to improve the performance of AHSS include different processing options and alloy additions to modify characteristics of the steel, but the processes tend to include lengthy thermal cycles. Also, heavily alloyed steels tend to be costly, are often difficult to roll into sheet and weld poorly.

Several Small Business Innovation Research (SBIR) grants that have been funded by the DOE Advanced Manufacturing Office and led by SFP Works, LLC are advancing Flash® Processing technology to produce high-strength, cold-stampable automotive steel from commercial off-the-shelf (COTS) steels. Several trial structural parts have been formed at lower projected cost and 30-

50% lighter weight while maintaining the same crash-test performance. The process produces heterogeneous transformation microstructures that are cold-formable, easily weldable and ideally suited to fabricate automotive parts.

The Process

Flash processing is an extremely rapid heat treatment with a total process time of less than 10 seconds (Fig. 1). Room-temperature or preheated steel is fed into an induction heating unit that heats the material at a rate of approximately 400°C/s to temperatures above 1000°C (1832°F).

The novel longitudinal flux heating coil uses electromagnetic induction heating to maximize temperature uniformity and heating rate. The material is above 1000°C for only about two seconds before it is flattened by water-cooled copper rollers. Upon exiting the rollers, the strip is sent to a submerged water quench, where several spray nozzles create highly turbulent flow for effective heat transfer, cooling the steel to near-ambient temperatures in less than one second and promoting a complex-transformation microstructure that includes martensite and, in some alloys, bainite. Unlike conventional transformation processing of steel, there is no tempering step.

Microstructural Development

Microstructures in Flash-processed steels depend on the initial microstructural heterogeneity and non-equilibrium conditions resulting from high heating rates, short austenitization time and high cooling rates.[2] While a wide range of steels have been Flash processed, producing steels with greater strength and higher ductility for a given strength, the details of the microstructural evolution are still an active and exciting area of research.

As shown in Figure 2, Flash processing AISI 1020 produces a seemingly uniform sheet with a tensile strength of 1,500 MPa. A commercially available martensite steel with the same tensile strength is shown for comparison. While a mixed martensite/bainite structure has been found in previous work,[2] thus far the microconstituents in low-alloy material that might explain its improved formability over that of traditionally treated steel are still the subject of ongoing research at The University of Tennessee.

A processing parameter that may help explain the unique properties of these materials could be temperature differences from non-uniform eddy currents. There is also some hardness heterogeneity across the thickness of some samples that does not seem to be solely due to chemical segregation. Previous research suggests hardness heterogeneity can lead to better spring-back performance and possibly formability.[3]

Mechanical Properties

Traditional steel processing is designed to produce a distribution of ferrite (body-centered cubic crystalline), martensite (body-centered tetragonal) and/or bainite (body-centered cubic) phase from a homogenized high-temperature austenite (face-centered cubic) phase. This is accomplished by exposure times of several minutes to hours at elevated temperatures in the range of 850-950°C (1562-1742°F) to allow for homogeneous chemical distribution within austenite.

SFP Works discovered that the mechanical properties of steel can be improved by a simple, but quick, high-temperature process that intentionally avoids the chemical homogenization during conventional austenitization. Figure 3 shows tensile strengths and specific strengths of several Flash-processed steels compared to a number of materials commonly used in the automotive industry to manufacture parts.

Flash-processed steels have higher specific strengths, meaning they are stronger per unit density than most other materials and can potentially provide lightweighting of automotive parts. Aluminum, by comparison, has a lower specific strength, which may be acceptable for a vehicle hood but would result in a heavier structural part.

Flash-processed steels also have excellent formability (Fig. 4). The total elongation of Flash® 1500 is very similar to Martensite 1500 but has a formability curve that closely resembles DP1000, a leading cold-stampable AHSS with typical elongation values of 10% compared to less than 7% for Flash 1500. While it matches the formability of DP1000, Flash 1500 is at least 30% stronger. In spite of its tensile strength, Flash 1500 is ductile enough to be cold pressed into shape without thinning or cracking and can achieve a 0T/1T bend radius. Ongoing research is focused on rationalizing these properties using detailed multiscale microstructural characterization.

Cold-Stamped Automotive Parts

Numerous automotive parts made from Flash-processed steel have been formed at room temperature using conventional stamping equipment in order to verify the high-rate manufacturing potential of the material, understand any unique formability issues and assess potential weight and cost savings.[4]

An automotive "crush can" made from 1.2-mm Flash 1500 is shown in Figure 5(a). Crush cans, typically located between the front or rear bumper reinforcements, are designed to absorb energy and collapse during impact. They are usually made of either DP780 steel or aluminum tubing and hydroformed into shape. The crush can made from Flash 1500 collapses to 0T to 1T bend radii, demonstrating its ductile response with no fragmentation. The Flash 1500 part also provides an estimated per part weight savings in excess of 30% due to the significantly higher yield strength.

Figure 5(b) compares a seat-track foot made from 3-mm-thick Grade-60 steel at 420 MPa on the left with a 1.2-mm-thick Flash 1500 seat-track foot on the right. Formability tests confirmed the seat foot made from Flash 1500 is 40% of the mass of the OEM part yet 50% stronger. Fatigue or other performance tests were not included in the formability test, but the test did confirm it is possible to room-temperature form Flash 1500 into a complex part in a stamping die.

The fuel shield, another energy-absorbing part, protects the fuel-system components during an impact should the force be great enough to push the engine into the vehicle's firewall. These parts are typically made from 3-mm-thick high-strength low-alloy (HSLA) steel with tensile strength of 550 MPa to both absorb energy and provide structural rigidity for safety.

A series of tests comparing a current production fuel shield with fuel shields made from three thicknesses of Flash 1500 (2.0 mm, 1.6 mm and 1.27 mm) were recently conducted by an automaker. The 2.0-mm Flash 1500 part performed just as well as the 3.0-mm HSLA 550 part, even at 120% of impact load. The 1.6-mm Flash 1500 fuel shield (Fig. 5c) performed as well as the 3.0-mm production part at 100% impact load. The tests demonstrated a 33% mass reduction at an improved cost per part, convincing the automaker to spec the material for the fuel shield in a near-term model-year vehicle.

Technology Outlook and Summary

Efforts to accelerate the commercialization of the Flash® process are under way. Recent tests confirm that AISI 1020 steels from five different mills produce Flash-processed steels with similar strength, formability and microstructure.

A pilot line is now under construction that will be able to Flash process 10-ton coils of steel in order to study and address scale-up issues such as product flatness and property uniformity. The new pilot line will allow these materials to be evaluated by automakers, qualifying the process to enable licensing of the technology. If these commercialization efforts are successful, the Flash process will require only a modest investment in new capital equipment, making it attractive for a wide range of potential suppliers to the automotive market.

With widespread use of Flash-processed steels, the U.S. automotive industry could save over 100 pounds of vehicle weight per car at reduced cost.[5] The potential of Flash-processed steels goes beyond the auto industry, however, with applications in agricultural machines and heavy equipment, rail, ships and defense systems with performance improvements, lower cost and lifetime energy savings possible in each application area.

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References

1. "Advancing Clean Transportation and Vehicle Systems and Technologies: Lightweight Automotive Materials," Chapter 8 of the Quadrennial Technology Review, U.S. Department of Energy, 2015. Available at: https://energy.gov/sites/prod/files/2015/12/f27/QTR2015-8D-Lightweight-Automotive-Materials.pdf
2. "Flash Processing Produces Unique Combination of Properties in Steels," D.J. Tung, T. Lolla, S.S. Babu, and G.M. Cola, Jr., *Advanced Materials & Processes,* November-December 2013, p. 48-50. Available at: http://amp.digitaledition.asminternational.org/i/211830-nov-dec-2013/50.
3. "Microstructural effects on the spring back of advanced high-strength steel," W. Gan, S.S. Babu, N. Kapustka, et al., *Metall. Materials Transactions* 37A (11), p. 3221-3231, 2006
4. "Replacing Hot Stamped, Boron, and DP1000 with 'Room Temperature Formable' Flash Bainite 1500 Advanced High Strength Steel," G.M. Cola, Jr., *Proceedings of the 28th ASM Heat Treating Society Conference,* p. 21-28, October 20-25, 2015
5. "Flash® Processed Steel for Automotive Applications," G.M. Cola, Jr., SFP Works, LLC, presentation at the U.S. DOE Advanced Manufacturing Office Program Review, Washington, D.C., June 14-15, 2016. Available at: https://energy.gov/sites/prod/files/2016/07/f33/P6%20-%20Flash%20Processed%20Steel%20for%20Automotive%20Applications_SFP%20Works_2016_compliant.pdf

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