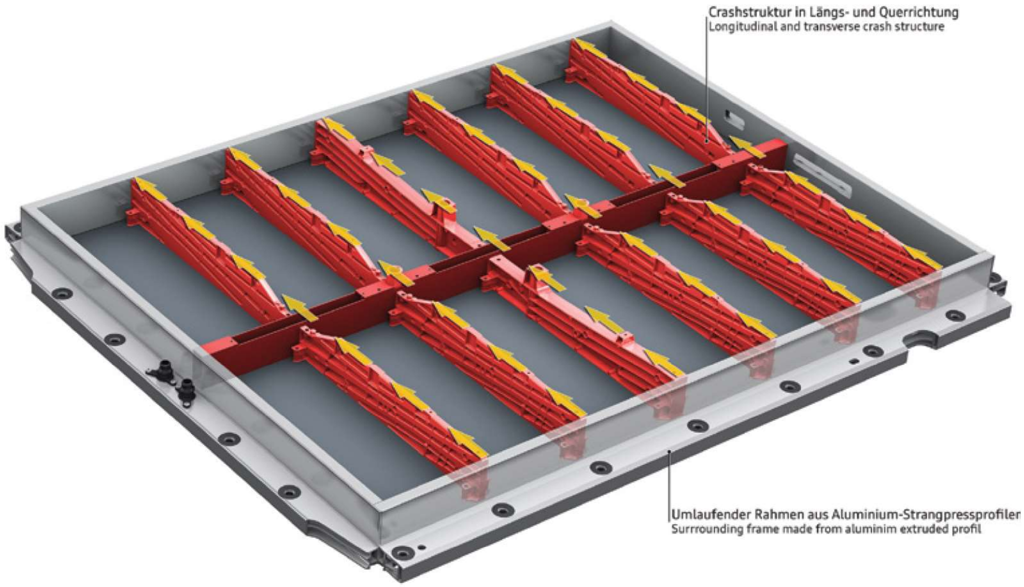
Lightweight steel on a (COLD) ROLL



Lightweight steels will compete with aluminum extrusions that have been an early choice for EV battery enclosures, such as seen on the 2020 Audi e-tron.

AUDI

A newly developed high-strength steel for cold stamping aims to beat aluminum for EV battery enclosures and other vehicle applications.

by Dr. Gregory Vartanov

Automotive OEMs are faced with the difficult task of significantly improving fuel economy and safety, while maintaining a competitive position in the market — as well as investing in the electrified future. This, among other benefits, can be accomplished by utilizing higher-strength steel in the production process. A newly developed and patented cold-roll high-strength steel for cold stamping, known as ColdStamp-Steel, is ideal for producing vehicle body-structure and safety components, including battery enclosures of electric vehicles (EV).

The microstructure of ColdStamp-Steel consists of one or more of martensite, ferrite, and retained austenite in different percentages, depending on the steel composition and heat treatment. Also, one or more of carbides, nitrides and carbonitrides are part of the microstructure. The resulting material offers high strength at moderate ductility and ColdStamp-Steel features a higher strength-to-weight ratio than commercial cold-rolled steels. Applications include vehicle bumper reinforcement beams, pillars, door impact beams, rocker panel inners and reinforcements, side-sill reinforcements, roof frame, beltline reinforcements and clips.

ColdStamp-Steel is offered in Grades 1-3, which are low-alloy compositions with the total alloying elements (except carbon) < 3.0 wt. %. Table 1 shows that Grade 1 has the lowest and Grade 3 the highest carbon concentrations. The manufacturing process principally consists of the following steps: melting of molten pig iron in a basic oxygen furnace, followed by vacuum degassing or melting of steel scrap in an electric arc furnace; continuous casting; hot milling; pickling; cold reduction; continuous anneal and quenching and tension leveling for flatness. ColdStamp-Steel can be manufactured as cold-rolled coils or cold-rolled sheets.

The product possesses formability that is suitable for cold stamping. A comparison of ColdStamp-Steel with three commercial cold-rolled, high-strength steels for cold stamping — SSAB's Docol 900M-1700M martensitic grades, ArcelorMittal's MartiNsite grades, and Kobo Steels' Kobelco grades — shows ColdStamp-Steel to be competitive. Table 2 shows the mechanical properties of Grade 1-3 of the ASTM standard tensile test in the longitudinal/roll (L) and transverse (T) directions at room temperature (r.t.).

Heat treatments

Several compositions of ColdStamp-Steel have been melted, hot- and cold-rolled, heat-treated, and tested. Two compositions of Grade 3 have the most desirable properties ("SC1 and SC2 compositions"). Table 3 shows that different heat treatments supply a wide range of mechanical properties to SC1 and SC2. These are applicable for different vehicle structural and safety components, as well as electric vehicle (EV) battery-enclosure structures.

The accompanying graphs show the r.t. engineering tensile stress diagrams of SC1 and SC2 after heat treatments. The ASTM standard tensile specimens with 2 in (50 mm) gauge were cut from the uncoated cold rolled SC1 of 0.06 in/1.50 mm thickness in the L direction. Those with 3.15-in (80 mm) gauge were cut from the uncoated cold-rolled SC2 of 0.04 in (1.0 mm) thickness in the L direction.

SC1 and SC2 can be coated by the commonly used processes, including galvanizing and aluminizing. Table 3 shows the heat treatments followed by those processes that can be applied without reduction of mechanical

	C (wt.%)	Mn	Si	P	S	Other
Grade1	0.18-0.22	<1.0	<1.0	<0.035	<0.03	Cr, Ti
Grade2	0.23-0.25	<1.0	<1.0	<0.035	<0.03	Cr, Ti
Grade3	0.26-0.30	<1.0	<1.0	<0.035	<0.03	Cr, Ti

Table 1.

		$E/10^3$ ksi/MPa	YS ksi/MPa	UTS ksi/MPa	El %
Grade1	L	21.0-26.0/ 145-180	170-180/ 1175-1240	185-200/ 1275-1380	>10
	T		175-185/ 1210-1275	190-205/ 1310-1415	>8
Grade2	L	23.0-28.0/ 160-190	200-210/ 1380-1450	220-230/ 1520-1590	>7
	T		205-215/ 1415-1485	225-235/ 1550-1620	>6
Grade3	L	27.0-31.0/ 186-215	195-215/ 1380-1485	220-265/ 1520-1830/	>4
	T		210-260/ 1400-1500	225-270/ 1550-1860	>4

Table 2, wherein E, YS, UTS, and El are a modulus of elasticity, a yield strength (0.2% offset), an ultimate tensile strength, and a total elongation.

	No	Heat treatment	$E/10^3$ ksi/MPa	YS ksi/MPa	UTS ksi/MPa	Strain in/in
SC1	1	Q+LT: Quenching and low tempering	18.8/ 130	186/ 1280	264/ 1820	0.095
SC1	2	Q+HT: Quenching and high tempering	26.9/ 186	170/ 1170	180/ 1240	0.09
SC1	3	N+Q+LT: Normalizing, quenching and low tempering	31.8/ 220	257/ 1775	295/ 2035	0.025
SC2	4	Q+LT: Quenching and low tempering	26.4/ 182	218/ 1500	246/ 1700	0.089
SC2	5	Q+HT: Quenching and high tempering	28.1/ 194	170/ 1175	182/ 1255	0.052

Table 3, heat-treat specifications of the SC1 and SC2 materials.

	SC2	7075
Density (ρ), (lb/in^3)/ (g/cm^3)	0.281/7.81	0.102/2.81
$E/10^3$, ksi/MPa	28.2/194.6	10.4/71.8
Specific stiffness (E/ρ) / 10^4	10.036/2.490	10.196/2.555
Yield strength (YS), ksi/MPa	217/1500	72/500
Specific yield strength (YS/ρ)	772/192	706/178
Ultimate tensile strength (UTS), ksi/MPa	246/1700	85/585
Specific tensile strength (UTS/ρ)	875/218	833/208
Total elongation, %	5	8

Table 4, comparison of the r.t. mechanical properties of the SC2 sheets and the 7075 AL alloy sheets hardened to the highest strength.

properties. Comparisons of SC1 and SC2 with the commercial high strength cold-rolled steels show that after high tempering at 1,000-1,050°F, only SC1 and SC2 possess the tensile strength of more than 175 ksi/1200 MPa and elongation of 9-10%. Quenched and high-tempered SC1 and SC2 can be galvannealed without reduction of their mechanical properties.

SC1 and SC2 can be welded by the conventional spot welding with the adapted parameters. Given the increase in carbon concentration, it is necessary to increase the welding force and adapt welding cycles to achieve high quality spot welding. SC1 and SC2 possess the carbon equivalents CEVM=%C + (%Mn + %Si)/6 + (%Cr + %Mo+%W + %V+%Ti)/5 + (%Ni + %Cu)/15 of ~ 0.975 and ~0.61. Cold-rolled Docol 1700M steel, by comparison, has the carbon equivalent of ~1.26. An initiative is underway to improve the SC1 and SC2 by reducing the carbon equivalent below 0.60 without the reduction of their mechanical properties.

EV battery enclosures

Aluminum (AL) alloys have become the dominant material for battery enclosures used in EVs due to their low density and acceptable strength. AL battery enclosures, or other platform parts, typically provide weight savings of ~40% compared to equivalent commercial steels. Traditionally, the best-suited AL alloys for battery enclosures are 6000- and 7000-series and similar alloys.

Despite its light weight and recyclability benefits, AL alloys have a crucial disadvantage if the heat generated by the battery cells raises the temperature of battery enclosures above 600°F (315°C). At more than 300-sec exposure at 600°F or higher, the yield strength drops by more than 70%, especially for parts that are in direct contact with the battery cells. Furthermore, in critical situations of fire at about 2,200°F (1,205°C), the battery enclosures fail within ~5 sec, creating a paramount safety concern for EV occupants. Regarding thermoplastics and composite materials, their use in battery enclosures is challenged by cost and by temperatures much less than 600°F.

Increasing the battery capacity, a primary focus of EV developers, increases the probability of battery failure, including overheating and possibility of explosions. To eliminate the potential harm to EV passengers, it is necessary to utilize more robust material than AL alloys. Galvanized and aluminized ColdStamp-Steel, particularly SC2, is an attractive material to be used in EV battery enclosures. Steel sheet can be substituted for enclosures made from high-strength AL alloy sheet without increasing the structure's weight, while improving safety, durability and longevity. Per-pound production cost of high-strength AL alloy sheets is more than 100% higher than the cost per pound of galvanized and aluminized ColdStamp-Steel sheets.

A comparison of the specific stiffness, specific yield strength and specific ultimate tensile strength (ratios of stiffnesses and strengths to density) of SC2 and 7075-T6 (Table 4) shows that the steel can be substituted for any high-strength AL alloy without increasing the weight of the battery enclosures, as the thickness of SC2 sheet is 2.8 times less than the thickness of 7075-T6 sheet.

ALL TABLES: AMD CORP.

AMD metallurgy expands materials choice

Dr. Gregory Vartanov.

Dr. Gregory Vartanov is chief engineer at Advanced Materials Development Corp., a privately-owned Toronto, Canada-based company that develops high-strength steels and alloys for the automotive, aerospace and defense industries. He holds an M.S. and Ph.D. in materials engineering and metallurgy. Dr. Vartanov has been granted five U.S. patents in high-strength steel alloys and he has authored numerous engineering articles in the U.S. He spoke recently with SAE editor Lindsay Brooke.

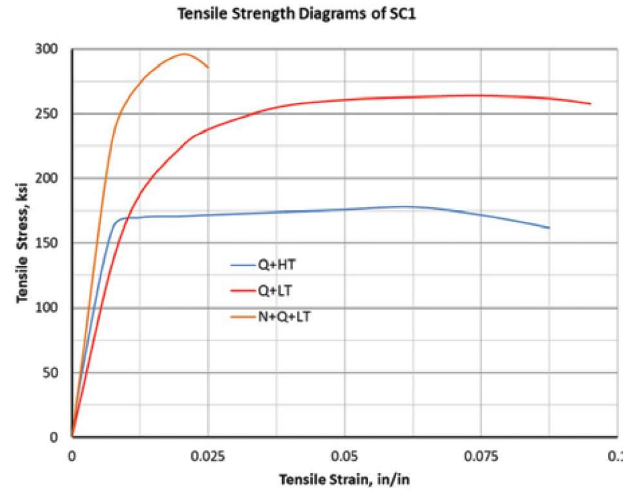
AMD Corp. may be new to some SAE readers. Your focus to date has been in aerospace.
Yes. Our company has been in the auto industry about two years. We're now working on ColdStamp-Steel sheet for automotive.

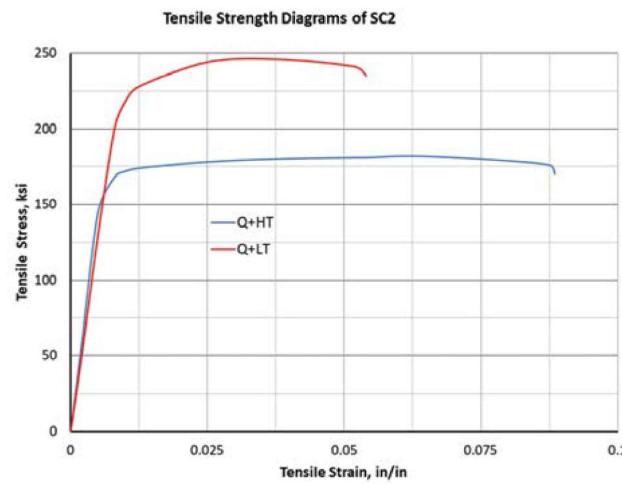
What are ColdStamp's primary advantages?
Our material offers a very competitive balance of strength, ductility, weldability and cost-effectiveness compared with other steel alloys such as Docol, MartiNSite, and Kobelco, and with aluminum alloys. ColdStamp-Steel gives vehicle makers another choice in high-strength materials. Currently, it's being evaluated at one North American company for possible implementation.

EV battery enclosures are an increasingly competitive area for materials, as well as EV structures overall. Aluminum is targeting that business aggressively.
High-strength aluminum alloys become weaker as the service temperature rises. They melt at about 1,260 degrees [F] and it have lost half of their strength or more by the time they reach 600 degrees. For example, the ultimate tensile strength of 6061-T6 is about 45 KSI at room temperature, but is only about 4.6 KSI at 600°F. Even at only 400°F its strength is only 19 KSI. Our steel increases the safety of EV battery structures due to its better thermal performance.

Cold-stamped steel also enables use of thinner wall material for the same amount of strength, correct?
Yes. For example, a 1-mm-thick sheet of ColdStamp-Steel has the equivalent strength of a 2.8-mm-thick sheet of 7075-T6 or 5-mm plate of 6061-T6. The cost of the high-strength aluminum alloys is 100% higher than the cost of ColdStamp-Steel.

For more information, see http://amdoncorp.com/.





Room temperature engineering tensile stress diagrams of SC1 and SC2 after heat treatments.

ColdStamp-Steel can be coated in several ways. It can be galvanized by electroplate or hot-dip processes, which supply durability at long-term continuous exposures with the maximum temperature of up to 392°F (200°C). Continuous exposure to temperatures above this can cause the outer free zinc layer to peel from the underlying zinc-iron alloy layer. Galvanized ColdStamp-Steel (compositions SC1 and SC2) possesses the mechanical properties as shown in Table 3 with some corrections on the added galvanic layers; corrosion resistance of the galvanized ColdStamp-Steel competes with the corrosion resistance of high-strength AL alloys. Cost of production per pound of 6000-series and 7000-series AL alloy sheet is more than 100% higher than the cost per pound of the galvanized SC1 or SC2 sheets.

After quenching and high tempering at 1,000-1,050°F, SC1 and SC2 possess tensile strength of more than 175 ksi (1,200 MPa) and elongation of 9-10%; quenched and high-tempered SC1 and SC2 can be galvannealed without reduction of their mechanical properties. Cost of the galvannealed ColdStamp-Steel is slightly higher than the cost of the hot-dip galvanized alloy.

ColdStamp Steel, coated by electroplating or hot-dip processes, offers definitive benefits for use in battery-enclosure applications. The aluminized, galvannealed and galvanized ColdStamp-Steel can prevent failure of battery enclosures at temperatures of up to 1,400°F (760°C) and withstand fire up to 2,200°F (1205°C), allowing for more time for EV passengers to evacuate in the event of an emergency. Durability of battery enclosures made from the aluminum alloys cannot compete with the durability of enclosures of the same weight made from coated ColdStamp-Steel at ambient and elevated temperatures. And the cost of of aluminized ColdStamp-Steel sheet currently is half that of 6000- and 7000-series AL sheet. ■