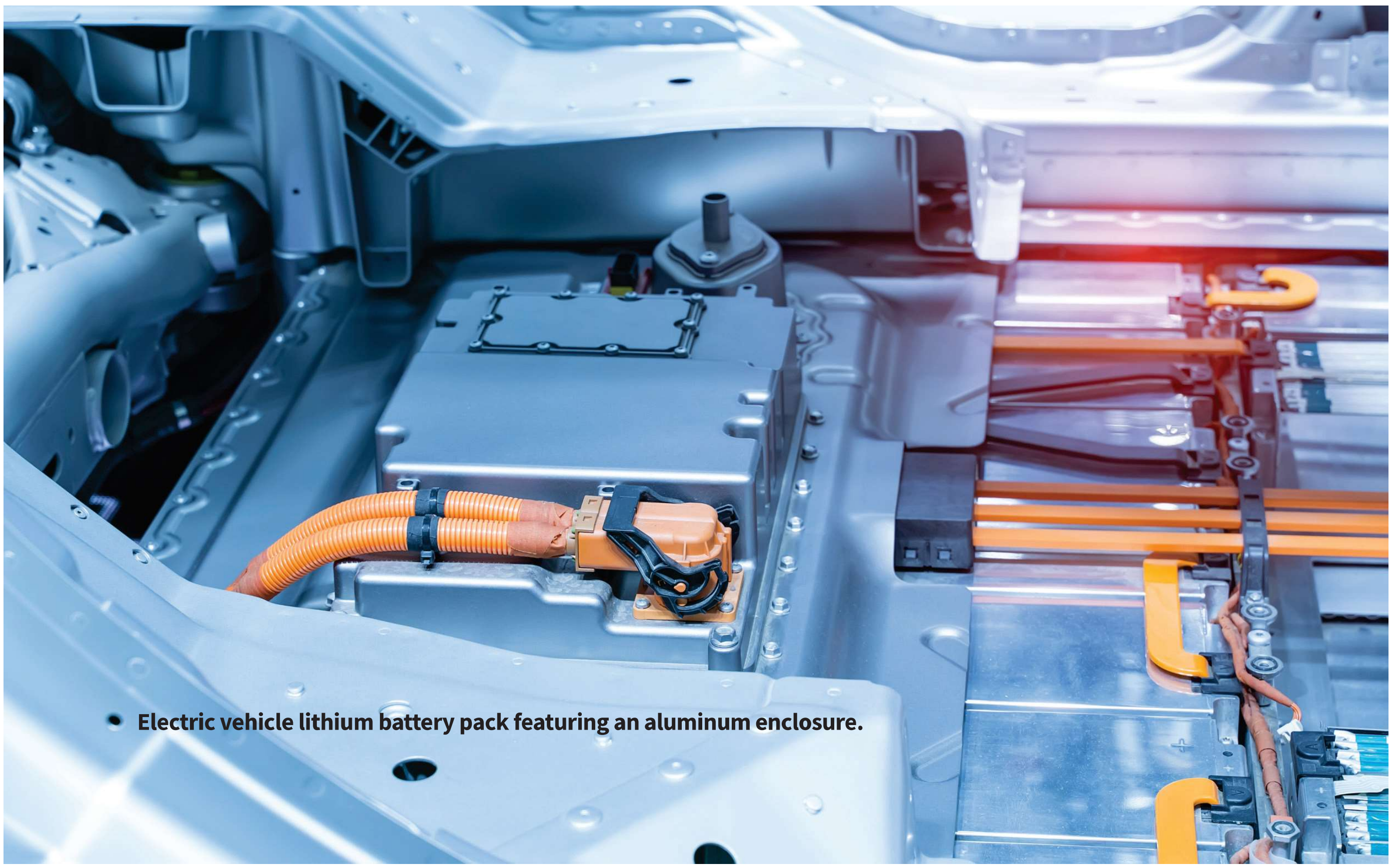
HIGH-STRENGTH STEEL FOR ELECTRIC VEHICLES

A new high-strength steel developed for cold stamping addresses the challenges presented by materials traditionally used to manufacture electric vehicle components.



Electric vehicle lithium battery pack featuring an aluminum enclosure.

In recent years, aluminum alloys have become the dominant material for structural and safety components in electric vehicles (EVs)—including battery enclosures—due to their low density and acceptable strength. Traditionally, the aluminum alloys best suited to EVs are 5000 and 6000 series alloys[1].

Despite their light weight and recyclability benefits, aluminum alloys have a crucial disadvantage if the heat generated by the battery cells raises the battery enclosure temperature above 600°F (315°C). With over 300 seconds of exposure at 600°F (315°C) or higher, the yield strength of the aluminum alloy drops by more than 70%, especially in parts that are in direct contact with battery cells. Further, in critical situations of fire at about 2200°F (1205°C), battery enclosures fail within approximately 5 sec, creating a paramount safety concern for EV occupants. Alternatives to aluminum alloys include thermoplastics and composite materials, but these are not often used in battery enclosures due to high cost and challenges with performance in temperatures above 600°F (315°C).

A patented, cold-rolled high-strength steel for cold stamping (ColdStamp-Steel)[2] has been developed to address the challenges presented by conventional materials. For production of EV structural and safety components, ColdStamp-Steel offers high strength at moderate ductility and possesses a higher strength-to-weight ratio than commercial cold-rolled steels and high-strength aluminum alloys.

DESCRIPTION

ColdStamp-Steel is a low alloy steel with the total alloying elements (other than carbon) < 3.0 wt%. The steel is hardened by quenching and tempering at temperatures of 300° to 1060°F (150° to 571°C). The manufacturing process principally consists of the following steps: melting of molten pig iron in a basic oxygen furnace; vacuum degassing or melting of steel scrap in an electric arc furnace; continuous casting; hot milling; pickling; cold reduction; continuous annealing and quenching; and tension leveling for flatness. ColdStamp-Steel can be manufactured as either cold-rolled coils or sheets in uncoated, galvanized, and galvannealed product variants.

The new steel 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 1200M-1700M martensitic grades[3], ArcelorMittal's MartINsite grades[4], and Kobo Steel's Kobelco grades[5]—shows it to be competitive with the lineup.

MECHANICAL PROPERTIES

Several compositions of ColdStamp-Steel have been melted, hot and cold rolled, heat treated, and tested. One composition in particular possesses the most desirable mechanical properties for EV component manufacturing. Figure 1 shows the engineering tensile stress diagrams of that composition after two heat treatments: quenching and low tempering (Q+LT) at 450°F (232°C); and quenching and high tempering (Q+HT) at 1020°F (549 °C). The ASTM standard tensile specimens with 3.15-in. (~80-mm) gauge were cut from the uncoated cold-rolled sheets with 0.04-in. (~1.0-mm) thickness in the longitudinal direction, and the specimens were tested according to the ASTM standard at room temperature.

The different tempering temperatures applied to ColdStamp-Steel produce high-strength mechanical properties suitable for safety and structural components. This distinguishes it from commercial high-strength steels that possess only one strength and ductility level.

COATINGS

After quenching and low tempering, ColdStamp-Steel can be electrogalvanized without reducing strength and ductility. After quenching and high tempering, it can be hot-dip galvanized and galvannealed.

A comparison of ColdStamp-Steel with commercial high-strength cold-rolled steels shows that after high tempering at 1000° to 1050°F (538° to 566 °C), only the proposed steel has a tensile strength of 180 ksi (1240 MPa) or higher, and elongation of 9-10%. This suggests that ColdStamp-Steel can be hot-dip galvanized or galvannealed without any reduction of its mechanical properties.

Ambient corrosion resistance of the galvanized and galvannealed ColdStamp-Steel competes with the corrosion resistance of high-strength aluminum alloys, while high-temperature corrosion and oxidation resistance is significantly higher for the new steel.

WELDABILITY

ColdStamp-Steel can be welded through conventional spot welding using the adapted parameters. Given the increase in carbon concentration, it is necessary to increase the welding force and change welding cycles to achieve high-quality spot welding.

The proposed composition of ColdStamp-Steel possesses the carbon equivalents CEVM = %C + (%Mn + %Si)/6 + (%Cr + %Mo+%W + %V+%Ti)/5 + (%Ni + %Cu)/15 of around 0.61, wherein the element concentrations are in wt%. By comparison, one widely used, commercial cold-rolled steel has the carbon equivalent of approximately 1.26. An initiative to improve ColdStamp-Steel by reducing the carbon equivalent below 0.60 without reducing its mechanical properties is now underway.

COST COMPARISON

The price quoted in June 2021 by a U.S. manufacturer of cold-rolled hot-dip galvanized ColdStamp-Steel sheets with 0.04-in. (~1.0-mm) thickness is $1980-$2080/ton, whereas the price of the 6082-T6 aluminum alloy sheet with 0.12-in. (~3.0-mm) thickness is $4100-$4200/ton.

BATTERY ENCLOSURES

A primary focus of EV developers is to increase battery capacity, but this increases the probability of battery failure, including overheating and the possibility of explosions. To eliminate potential harm to EV passengers, it is necessary to use material that is stronger at ambient and elevated temperatures than aluminum alloys. Hot-dip galvanized and galvannealed ColdStamp-Steel is a suitable alternative for materials used in EV battery enclosures. Without increasing the structure's weight, ColdStamp-Steel offers a low-cost alter-

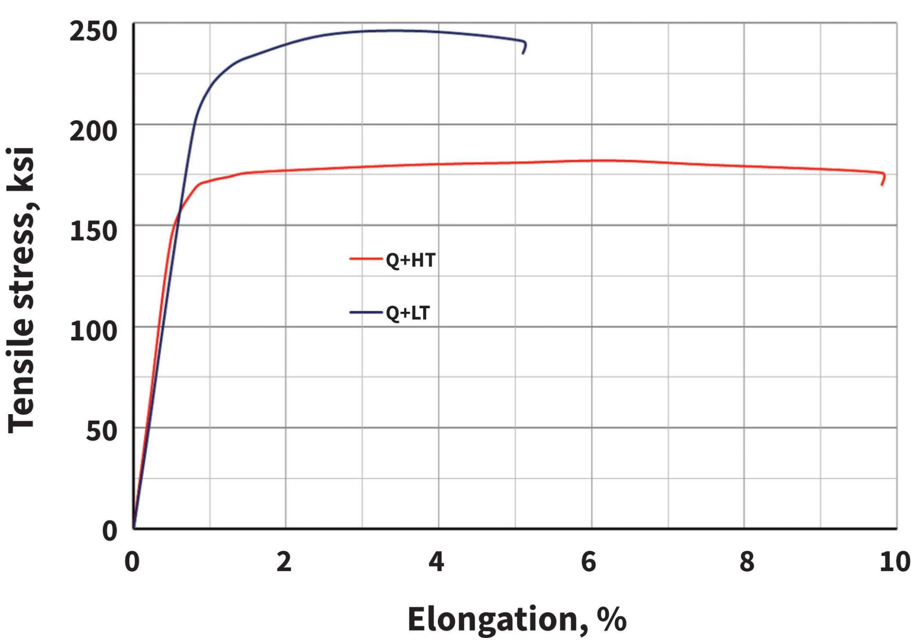


Fig. 1 — Engineering tensile stress diagrams of a ColdStamp-Steel composition after two heat treatments: quenching and low tempering (Q+LT) at 450°F (232°C); and quenching and high tempering (Q+HT) at 1000°F (538°C).

native to high-strength aluminum alloys while improving strength, safety, durability, and longevity.

Table 1 provides a comparison of the density (ρ), modulus of elasticity (E), specific stiffness (E/ρ), yield strength (YS), specific yield strength (YS/ρ), ultimate tensile strength (UTS), specific ultimate tensile strength (UTS/ρ), and total elongation (El) of the Cold-Stamp-Steel detailed in Fig. 1 with high-strength 6082-T6 and 7075-T6 aluminum alloys.

Battery enclosures made of the electro-galvanized ColdStamp-Steel sheets of 0.04-in. (~1.0-mm) thickness can substitute for the same or higher weight battery enclosures made of 6082-T6 aluminum alloy sheets of 0.2-in. (~5.0-mm) thickness, while stiffness, strength, and durability of the steel enclosures are significantly higher.

Battery enclosures made of the hot-dip galvanized or galvannealed Cold-Stamp-Steel sheets of 0.04-in. (~1.0-mm) thickness can substitute for the same or higher weight enclosures made of 6082-T6 aluminum alloy sheets of 0.12-in. (~3.0-mm) thickness. The strength and durability of steel enclosures are higher.

ColdStamp-Steel, coated by electroplating or hot-dip processes, offers certain benefits for use in battery enclosure applications. The hot-dip galvanized and galvannealed Cold-Stamp-Steel can prevent failure of battery enclosures at temperatures up to 1000°F (538°C), as well as withstand fire up to 2200°F (1205°C), allowing more time for EV passengers to evacuate in case of an emergency. The durability of battery enclosures made of aluminum alloys cannot compete with the durability of enclosures of the same weight made of coated ColdStamp-Steel at ambient and elevated temperatures.

BATTERY ENCLOSURE DESIGN

The proposed design is based on a concept wherein the battery enclosure is an integrated part of the car body-in-white (BIW) and the battery is placed directly in the BIW. This design allows for increased stiffness, strength, and durability of the entire BIW, as well as battery safety.

ColdStamp-Steel can be used as the primary material for the new enclosure design. The enclosures made of this steel have the following advantages compared to high-strength aluminum alloys, including the strongest 7075-T6 aluminum alloy: the same ambient temperature and significantly higher elevated temperature corrosion resistance; better weldability; the same or less weight; the same or higher specific stiffness and strength; safety of EV passengers in case of overheating or fire; and 40-50% material cost savings.

Concurrently, a comparison of ColdStamp-Steel with the commercial high-strength steels demonstrates its combination of higher strength and ductility, weldability by spot welding, and galvanizing (including electro, hot- dip) and galvannealing. Several enclosure designs made of the hot-dip galvanized and galvannealed ColdStamp-Steel sheets with different thicknesses have been computer modeled. An example of the optimum design with low weight and high stiffness and durability is described below.

The enclosure's dimensions are 5 x 50 x 65 in. (127 x 1270 x 1651 mm). It consists of a top cover made by cold stamping from the 0.025-in. (0.635-mm) thickness sheet of approximately 23 lb (10.5 kg) weight; a crash structure made by welding from the 0.04-in. (~1.0-mm) thickness sheet of approximately 36 lb (16.4 kg) weight; a housing tray made by cold stamping from the 0.025-in. (0.64-mm) thickness sheets of approximately 30 lb (13.6 kg) weight; a battery frame made by stamping and welding from the 0.04-in. (~1.0-mm) thickness sheet of approximately 34 lb (15.5 kg) weight; a cooling system made of the 6082 aluminum alloy of approximately 12 lb (5.5 kg) weight; and a bottom cover made by cold stamping from the 0.025-in. (0.64-mm) thickness sheet of approximately 23 lb (10.5 kg).

The enclosure has a total weight of approximately 158 lb (72 kg), which is similar to enclosures made of aluminum alloys. At the same time, the enclosure features strength, stiffness, durability, and lifetime that are significantly higher than any high-strength aluminum alloy enclosure.

The cost of 146 lb of galvanized ColdStamp-Steel and 12 lb of 6082 aluminum alloy used for the steel enclosure

TABLE 1 – PROPERTIES OF COLDSTAMP-STEEL COMPARED TO HIGH-STRENGTH 6082-T6 AND 7075-T6 ALUMINUM ALLOYS

Materials		ColdStamp-Steel		6082	7075
Heat treatment		Q+LT	Q+HT	T6	T6
ρ	lb/in^3	0.282	0.282	0.098	0.102
	g/cm^3	7.800	7.800	2.710	2.810
E	ksi	28100.0	26400.0	10152.7	10442.7
	MPa	193742.5	182021.4	70000.0	72000.0
E/ρ	$ksi/(lb/in^3)$	99718.6	93685.8	103699.0	102866.1
	$MPa/(g/cm^3)$	24838.8	23336.1	25830.3	25622.8
YS	ksi	217.0	170.0	37.7	73.0
	MPa	1496.2	1172.1	260.0	503.0
YS/ρ	$ksi/(lb/in^3)$	770.1	603.3	385.2	718.6
	$MPa/(g/cm^3)$	191.8	150.3	95.9	179.0
UTS	ksi	246.0	182.4	45.0	83.0
	MPa	1696.1	1257.6	310.0	572.0
UTS/ρ	$ksi/(lb/in^3)$	873.0	647.3	459.2	817.2
	$MPa/(g/cm^3)$	217.4	161.2	114.4	203.6
El	%	5.1	9.7	8.0	7.0

is about $154, while the cost of 158 lb of 6082-T6 aluminum alloy used for the aluminum enclosure is around $278.

CONCLUSION

ColdStamp-Steel is a newly developed steel for cold stamping EV structure and safety components, including battery enclosures. Battery enclosures, such as the one proposed here made of galvanized ColdStamp-Steel, can be substituted for enclosures made of high-strength aluminum alloys without increasing their weight and while improving stiffness, strength, and durability. **~AM&P**

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References

1. New Steel Sheet Available for Cold Stamping, *Advanced Materials & Processes,* p 9, April 2016.

2. R. Gehm, Constellium Develops New Alloys for EV Battery Enclosures, *Automotive Engineering,* February 19, 2021, www.sae.org/news/2021/02/constellium-aluminum-ev-battery-enclosures.

3. Docol 1700M, data sheet, November 26, 2019, www.ssab.com/products/brands/docol/products/docol-1700m.

4. MartINsite, data sheet, 2019, https://usa.arcelormittal.com/~/media/Files/A/Arcelormittal-USA-V2/what-we-do/price-list/2019-03-datasheet-martensitic-final.pdf.

5. Kobelco, data sheet, 2019, www.kobelco.co.jp/english/products/download/steel-aluminum/files/cold1300_1700hi.pdf.