

Environmental Footprint of Aluminum and Steel BEV Battery Pack Structures under Equivalent Crash Performance

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Battery electric vehicles (BEVs) are expected to reduce greenhouse gas (GHG) emissions during vehicle operation. However, the installation of battery systems increases vehicle mass, which may reduce driving range. Therefore, BEV battery packs are required to achieve both lightweight design and adequate battery protection. Aluminum alloys are effective for reducing structural weight, whereas their GHG emissions during material production are generally higher than those of steels. Therefore, the environmental benefit of material selection should be evaluated from a life cycle perspective, including material production, battery production, and vehicle use.

In this study, steel and aluminum BEV battery pack models were designed to achieve equivalent crash performance. An E-segment SUV BEV concept vehicle developed in a previous study was used as the reference vehicle, and the battery pack design space was defined as 2220 mm × 1460 mm × 157 mm. The material configurations and structural layouts of the steel and aluminum battery pack models are shown in Fig. 1. The steel models employed 1180 MPa-class and 1470 MPa-class high-strength steels for structural members, whereas the aluminum models employed 6000-series and 7000-series aluminum alloy extrusions. Side pole impact test conditions were simulated using a battery-pack-level finite element model. The structural specifications were determined such that deformation of the battery cell module did not exceed 5 mm under a load input of 270 kN.

All battery pack models satisfied the target cell protection requirement under the side pole impact condition. Under the equivalent crash performance requirement, the aluminum models were approximately 40% lighter than the steel models. In addition, the maximum battery packaging volume of the aluminum models was approximately 5% larger than that of the steel models. This increase was attributed to the higher design flexibility of aluminum extrusion-based structures.

Life cycle GHG emissions were evaluated for the designed battery pack models. The system boundary included material production, parts manufacturing, vehicle manufacturing, battery production, and vehicle use. GHG emissions associated with vehicle manufacturing were assumed to be unaffected by the battery pack material. The aluminum models exhibited higher GHG emissions than the steel models during material production because of the higher emission intensity of aluminum alloys. However, this increase was partly offset by reductions in GHG emissions during battery production and vehicle use resulting from the lighter battery pack structure. Fig. 2 shows the breakdown of GHG emission changes from Steel A to Steel B and from Steel A to Aluminum B.

These results indicate that the environmental performance of BEV battery pack materials cannot be assessed solely on the basis of GHG emissions from material production. Lightweight design can reduce both the required battery capacity and energy consumption during vehicle use, and these effects should be considered from a life cycle perspective. As low-carbon production technologies for both steels and aluminum alloys become increasingly available, the importance of lightweight battery pack design is expected to increase regardless of material choice.

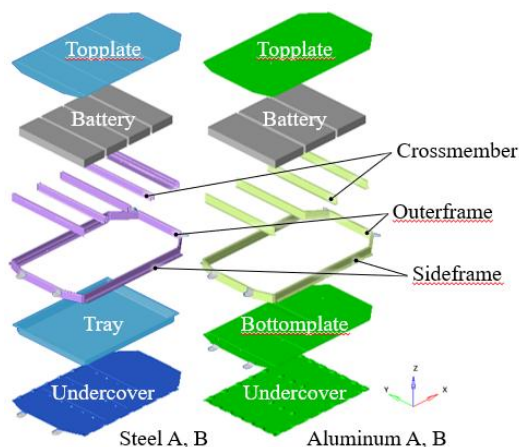


Fig.1 Material configurations of steel and aluminum models

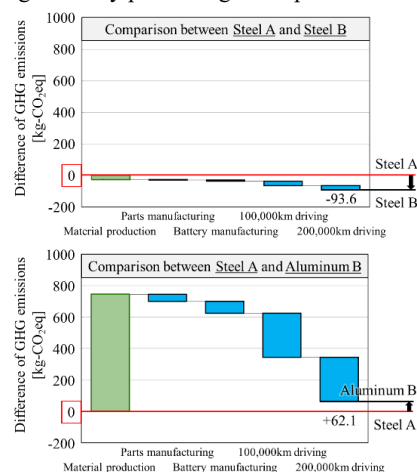


Fig.2 GHG emission change breakdowns from Steel A to Steel B and from Steel A to Aluminum B