Hot Form Quench Enables Complex, Lightweight Structures in High Strength Aluminum

Further improvements in the lightweight design of vehicles provide automakers the opportunity to meet emission targets and improve performance. Achieving this requires not only the development of new materials, but also new forming methods. Unless a novel material can be formed economically, predictably, and sustainably, it is rendered useless for all but niche applications. In the quest for lighter, stronger, and cheaper structures, engineers have generally been able to secure just two of these three target attributes.

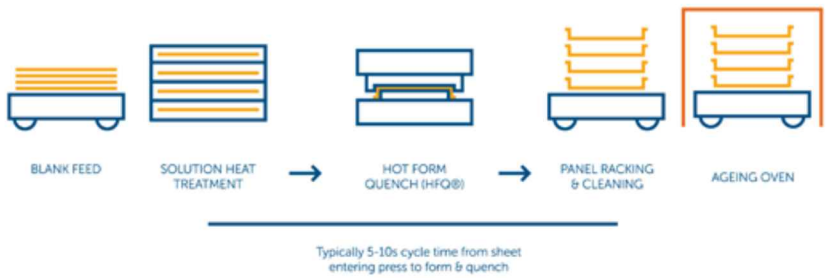

Figure 1. Overview of the HFQ process steps.

The University of Birmingham and Imperial College, London started its groundbreaking research on the viscoplastic forming of ultra-high-strength grades of aluminum in 2003. Ten years of materials characterization, modeling, and validation testing culminated in the development of the Hot Form Quench (HFQ®) technology, which addresses problems surrounding poor formability in 2xxx, 6xxx, and 7xxx series aluminum alloys. HFQ is a viscoplastic forming technology for the high speed production of complex and deep drawn components in ultra-high strength grades of aluminum sheet. The first automotive applications were launched by Impression Technologies in 2016 with 6xxx series deep drawn structural parts on the Lotus Evora and Aston Martin DB11. Since then, the adoption of HFQ technology is accelerating, particularly in the electric vehicle (EV) segment.

HFQ is fast becoming widely accepted as a new standard for complex shape forming of aluminum sheet, within both automotive and aerospace applications. Multiple new investment projects in Europe and Asia are installing HFQ process production lines in order to supply complex components for new automotive models. This article discusses some of the main areas of recent commitment by OEMs, Tier 1 suppliers, and aluminum companies. In addition, the article presents insights into new HFQ applications and technology developments.

Technology Overview

HFQ involves heating aluminum sheet to its solutionizing temperature before rapid forming and simultaneous in-die quenching (Figure 1). This is followed by any necessary second trimming or rapid artificial aging operations. The technology is supported by a software plug-in (an HFQ Module) that supports forming simulation and tool face design.

While there are some similarities to the processing of press-hardened steel (PHS), which is currently commonplace in the stamping industry, the HFQ process provides some significant technical differences in heating technology, lubrication, tooling, simulation, and secondary heat treatment when dealing with aluminum sheet. In addition, it should be noted that the HFQ technology is a hot forming process for aluminum in the range of 350-600°C, compared to warm forming, which is an isothermal forming process carried out at around 200-300°C. Warm forming typically results in a limited amount of formability, increased springback, and different mechanical properties versus HFQ. Another comparable aluminum sheet forming process is superplastic forming, a hot gas stretch forming process that has been available since the 1970s. Superplastic forming is able to provide high part complexity, but has long cycle times (normally 2–10 minutes or longer) and is restricted to alloys with controlled grain size.

The HFQ forming stage takes place at between 350 and 600°C with potential cycle times below 10 seconds. Cycle times are largely determined by the throughput capability of the solution heat treat furnace, which works well with high efficiency furnace designs, such as forced convection ovens that are not normally used for PHS. The forming press must be capable of forming at high speeds, which is possible with modern hydraulic and servo designs. Because of the extreme formability of HFQ, left- and right-handed parts can be formed double attached in a single blow, reducing tooling CAPEX, material waste, and operational costs.

HFQ is best suited for automotive components requiring high strength, increased part integration, and the high ductility required to achieve significant draw depth or tight radii (which includes up to around 30 components in a vehicle where aluminum is used). Ideal applications for HFQ include A and B pillars, cantrails, door/closure inners, door intrusion beams, rocker panels, cross members, single piece lamp cans and drain channels (for part integration), battery/charger boxes, and hoods for SUVs, EVs, and premium platforms. A-class surfaces, while possible in theory, are not yet available using the HFQ process. Also, for parts with simple geometries or requiring low strength aluminum grades, the standard cold forming method will be the most appropriate process, as it is cheaper, provides shorter cycle times, and implements simpler production equipment.

Validation Programs & Applications Expansion

Any new technology is adopted with caution by the automotive industry and tends to be applied first on a single component type in low volume platforms. Accordingly, Impression Technologies, for its first significant vehicle application worked with Aston Martin on the A pillars for the DB11 (Figure 2). The A pillars were produced using 6082 alloy, achieving a 310 MPa yield strength

Figure 2. A narrow high strength A pillar formed by HFQ in 6082 alloy on the Aston Martin DB11.

Figure 3. An HFQ safety cell representation based on the design used in the DBX. (Source: Impression Technologies.)

(and 11% residual elongation) with tight radii that allow for narrow bonding flanges, resulting in improved driver visibility. This first successful application proved to be a launch pad for wider adoption by Aston Martin into subsequent platforms, including the new DBX SUV, which incorporates a complete safety cell using nine parts formed with the HFQ technology (Figure 3).

With a view to preparing the technology for global adoption for high volume platforms, the Rapid Aluminium Cost Effective Forming (RACEForm) project was introduced in 2017. Backed by the U.K. government, the $12 million validation program included a group of participating companies, including Gestamp, Innoval, Imperial College, and Brunel University. The RACEForm project completed a series of successful trials on adapted high volume hot forming lines in mainland Europe. This project—coupled with other development and validation collaborations involving ESI, Novelis, and Telos Global (Figure 4)—brought the HFQ technology to a state of readiness for adoption by mainstream EVs and SUVs.

Figure 4. The hot forming line at Telos Global in Tennessee used for HFQ production trials in 7xxx series alloy.

The HFQ technology is now actively being used to produce 25 different parts on its first U.K. line, with a peak volume approaching 100,000 parts per year. With this demonstration of the technology's capability for high volume vehicles, Impression Technologies has embarked on a program of translating HFQ to a global ecosystem of Tier 1 partners and securing a new wave of components being developed for EVs being built by four different OEMs in Germany, the U.S., and China, the first of which will be launched in the coming 12 months. In most cases, the HFQ technology was adopted after it became clear to the OEM designers that target alloy grades would split (or fail) when formed using traditional cold or warm processes, requiring the implementation of complicated and costly multi-piece assemblies. HFQ provided a solution to this challenge by enabling part consolidation. Although full details cannot be disclosed at this time due to commercial confidentiality, the new wave of applications involves up to 50 new structural components comprised of various 6xxx and 7xxx alloys, as well as innovations in joining (which were necessary for the highest strength grades), hybridization with cast components, new surface treatments, and production on new purpose-built hot forming lines.

New advanced development programs have also started with a focus on structures for battery systems. The recently launched Lightweight Innovative Battery Enclosures using Recycled Aluminium Technologies (LIBERATE) project aims to utilize fully recyclable aluminum alloys in cost-effective battery enclosure designs. The project involves a consortium including Constellium, Innoval Technology, BMW, and Volvo, among others. Using HFQ and other advanced technologies, the new design will help lower part count and assembly time, improve tolerances, and reduce battery costs.

Moreover, HFQ is receiving widespread interest from battery enclosure designers, who are facing issues with package space and constraints of formability, cost, and system weight, which cannot be addressed entirely by existing technologies. Sealing, assembly, and manufacturing footprint are also major drivers for considering large HFQ stampings that offer high speed production and part integration (Figure 5). Many applications under discussion for battery and charger casings involve hybridization of HFQ sheet structures with castings and/or extrusions.

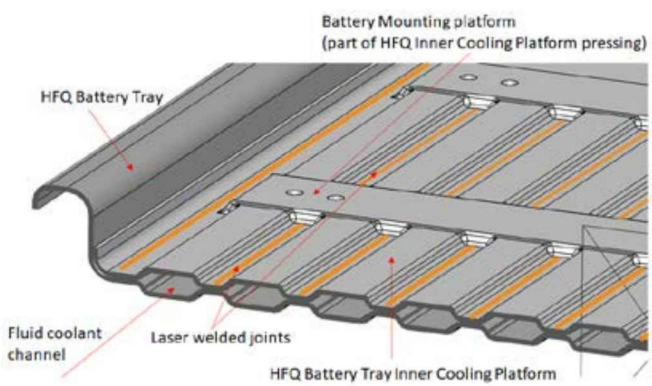

Figure 5. A low cost battery tray concept based on two HFQ stampings in aluminum that are laser welded to produce integrated cooling channels and stiffness. The strength of the alloy provides puncture resistance.

Development of a Lightweighting Ecosystem

A significant new technology with global applicability cannot be implemented successfully by a single company, as there are often many different competencies necessary to achieve scalability. Moreover, technologies that are held exclusively by a single supplier can limit widespread and rapid adoption. Therefore, the ambition for HFQ is to make a global lightweighting standard for high strength aluminum alloys that utilize the same manufacturing process recipe with a connected simulation software module (including a regular updated alloy material card library), which can be offered to a wide-ranging network of Tier 1 stamping companies and design houses.

Another essential part of this ecosystem will be matching capable press and furnace manufacturers together with alloy, joining, and simulation software suppliers. Among a growing list of companies working to provide HFQ solu-

tions to the automotive market are Novelis, Telos Global, ESI, Fischer Group, Jet Wagon, SDE Technology, UACJ, Atlas Copco, and EBNER. This unique model should be of benefit to OEMs, who stand to gain from the risk reduction and commercial leverage offered by the ability to choose between an array of global suppliers who match specific quality standards. OEMs, if desired, will also have the opportunity to embed HFQ technology within their own press lines.

The development of a Tier supply network that has access to a range of approved alloys is critical for OEM adoption of the HFQ technology. To this end three Tier suppliers have already signed agreements to build HFQ lines and offer supply for new vehicle platforms. Telos Global, based in Caryville, TN, carried out two sets of full line trials during 2019 for the manufacture of a 7xxx series door intrusion beam. The trials demonstrated the ability of the HFQ technology to achieve cycle times comparable or better than press-hardened steel, and cost models illustrated the economic proposition versus steel when the value of the weight is considered. In addition, Jet Wagon, a Tier supplier with a footprint across China, is in the process of building its first line for readiness in the second half of 2021. Fischer Group, based in Achern, Germany (but with a footprint in North America and China), is building its first line in 2021, with further lines already in the planning. It is expected that by 2023 there will be a choice of two to three Tier suppliers per region capable of offering HFQ to a common standard.

Impression Technologies will support the HFQ lightweighting ecosystem with applications engineering, training, and advanced alloy characterization, thus developing a particular alloy grade assured for use with the HFQ process. The alloy will have its own unique HFQ process settings and controls. It will also be included within the library of accredited grades within the HFQ simulation plug-in. In addition, simultaneous engineering and sourcing support will be provided to automotive OEMs that are looking to adopt high strength aluminum solutions.

Further Advances

Further enhancements to the capabilities of the HFQ technology are underway. Aside from continuous refinement of the core manufacturing process in order to improve cycle times, process capability, and secondary operations, there are two poles of activity—recycled alloys for high strength structures formed using HFQ and ultra-deep draw capability for the most demanding structures, which include battery trays and door inners. For recycled alloys, HFQ has already demonstrated very promising results with a variety of recycled feedstocks, most impressively with a 100% bottom-ash content alloy (Figure 6). Achieving high formability with such a feedstock reinforces the circular economy credentials of aluminum. With a 95% emissions saving versus primary stock, such aluminum could make a significant contribution to the reduction of embedded carbon within a vehicle. The next objective is to carry out a full set of validation trials using the alloy, ideally in partnership with an automotive OEM.

Continuing the theme of sustainable mobility, a new extra-high formability version of HFQ will be of particular benefit for new designs of battery trays, which have very tight internal radii and deep rectangular packaging constraints. Further announcements on the results of this work will be made in the coming year. The HFQ technology roadmap also includes advanced microstructural simulation, next generation aluminum alloys, and ultra-high throughput manufacturing.

Figure 6. Bottom ash from domestic waste incineration contains the remnants of packaging and is often reprocessed for low-grade aluminum structures. HFQ tests on 6xxx sheet produced from near 100% bottom ash are an early demonstration of the potential to use this low carbon feedstock for structural aluminum applications in vehicles.

Conclusion

Since its launch, HFQ has advanced in technology maturity, number of applications, and partnerships. It is ready for adoption for high volume vehicles, particularly EVs. A growing supply ecosystem working to a common standard is now installing production and engineering capability to support the automotive OEMs in their ongoing quest for cost-effective lightweight structures and lower embedded carbon. ■