Hot Form Quench (HFQ® Technology)

The new international standard for cost-effective automotive light-weighting using aluminium

Table of Contents

Executive summary

Environmental legislation to control emissions and reduce pollution continues to tighten across the globe. To meet these mandated challenges in the automotive sector, faith is increasingly being put in the use of battery electric vehicles, hybrids and more efficient internal combustion engine vehicles.

A key concern for developers in all of these technologies is a simple one: the weight (mass) of each vehicle contributes to the amount of energy needed to move it. Therefore, the race is on to reduce the weight of every type of vehicle and increase their efficiency, leading to reduced emissions, increased range and improved performance. 'Lightweighting', as it has come to be known, has never been more important for designers and manufacturers. This has, in turn, led to a sustained increase in the use of aluminium as the material of choice when manufacturing components, or even entire vehicle structures.

The use of aluminium to keep weight down is nothing new, but industry is on a constant mission to improve its structural strength, integrity, consistency, durability, safety and reduce cost. Moreover, manufacturers are always looking to make the material easier to work with, meaning improved, lower cost production processes that can use standard widely available alloys are a major focus of research. Any new process must balance all of these factors and operate increasingly efficiently, as well as affording a greater range of possibilities to a designer's imagination.

At Impression Technologies Ltd., we have developed and patented a truly innovative hot forming technology process and matching simulation capability which meets all of these challenges and offers a step-change in light-weighting potential, to automotive, aerospace, rail, industrial and many other sectors.

Our pioneering, unique and easy to adopt manufacturing process and forming simulation package, 'Hot Form Quench' (HFQ® Technology), sets a new international standard. This is the leading high speed process in the world that allows automotive OEMs to form deep-drawn and complex shapes from high and ultra-high strength aluminium, replacing the use of steel or low strength cold formed aluminium grades. Our process is rapid and meets the cycle times required for low-cost, high-volume manufacturing

In this white paper, we will examine how the HFQ® Technology works and how participating in the HFQ® Technology revolution can simplify vehicle design and boost production efficiency while also raising standards and driving the technological development of the lightweight vehicles of tomorrow.

We will also show how our experienced team of designers and process engineers are, right now, enabling automotive manufacturing businesses to deploy HFQ® Technology from the design phase, through to prototyping and manufacture using high-strength aluminium.

HFQ® Technology is here, making a difference, today.

Jonathan Watkins, CEO
Impression Technologies Ltd. (HFQ® Technology)

Introduction

HFQ® Technology is a new global standard encompassing the simulation, design and manufacturing of high-strength aluminium parts for the automotive industry. HFQ® Technology aims to advance global standards of aluminium processing, and, as a common solution for the entire supply ecosystem, facilitate cooperation and best practice sharing amongst OEMs, Tier 1s, aluminium producers and design software and equipment vendors.

The HFQ® Technology process delivers the following benefits:

- Uses high and ultra-high-strength grade aluminium to allow downgauging, replacing steel and lower strength aluminium
- Allows mass production of complex, deep drawn, high-strength aluminium parts with significant savings in cost and weight and reduced complexity
    - In typical volume automotive applications, HFQ® Technology delivers 20% reductions in weight versus lower strength aluminium and higher levels of cost reduction
- Consolidates aluminium parts due to improved formability with fewer operations
- Removes the requirement for reinforcement panels & can utilise tailor-welded blanks (further reduced weight, volume of materials and processing times)
- Removes the need for springback compensation in tool and part design (improved dimensional control)
- Combines heat treatment and pressing in a high speed operation which combines, solution heat treatment, forming, in-die quenching and age hardening
- Offers the potential to form highly recycled high-impurity material grades, which cannot be successfully formed cold
- Reduces number of stamping and downstream assembly operations, enabling reduced investment
- Enables tighter radii to achieve a constrained package

Easy to adopt for high volume applications:

- Uses existing press and tooling technologies and available aluminium alloys
- Cycle times meets requirement for low cost, high volume applications
- Single draw operation enables low investment in capex and tooling

By joining the HFQ® Technology ecosystem, your business will benefit from the latest on-going developments in advanced vehicle light-weighting standards.

Manufacturing with aluminium in the 21st century

Aluminium has already gained a foothold in the construction of vehicles, particularly with premium brands such as Rolls-Royce, Jaguar Land Rover, Audi, Aston Martin and Tesla. Ford has also pioneered the use of high-volume aluminium-bodied vehicles with its F-150 pick-up truck. According to the research agency Ducker Worldwide, aluminium content in cars is set to increase by up to 30% over the coming decade, driven by light-weighting in automotive manufacturing. Most significantly, by 2020, the prevalence of aluminium doors is estimated to reach a quarter of the total light vehicle market in the USA - in 2014, this number was just a fraction of one percent.

According to the latest report by Ducker [1], aluminium is increasingly being used in closures, bumpers, sub-frames and, specifically in the premium segment, the entire 'body-in-white' construction. Other aluminium products such as wheels, engine blocks and suspension components are now commonplace within the sector, however, using aluminium for sheet product in bonnets and body-in-white construction, within budgets, is highly desirable and will generate additional significant advantages for volume car makers.

A global community of the foremost OEMs, Tier 1 suppliers, aluminium producers and software and equipment suppliers has already begun to be built around Hot Form Quench (HFQ® Technology), accelerating the usage of this innovative technique and sharing best practices. Furthermore, this community – the HFQ® Partner Network - is pioneering a new worldwide standard that is constantly evolving thanks to the input and experiences from the world's leading automotive companies and engineers.

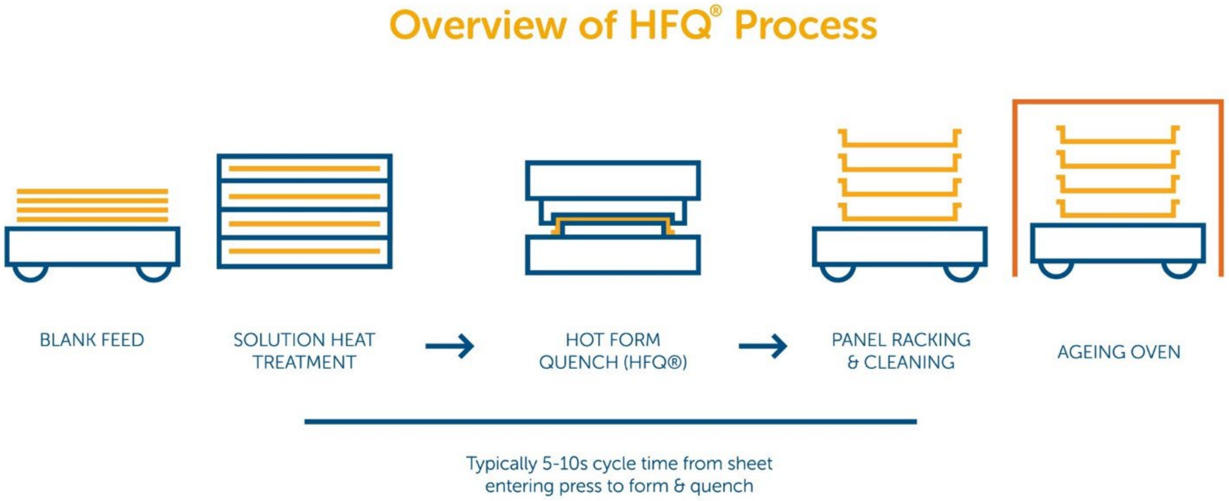
Having access to HFQ® Technology, you will gain access to a wealth of support services to assist you with your project which can help reduce cost and accelerate development times. HFQ® Technology will support you throughout the entire project lifecycle starting with guidance on how the technology can reduce part count, weight and springback issues in your designs, through to a detailed forming feasibility study for your application, followed by an assessment of how components made by HFQ® Technology could be produced through minor upgrades to existing press lines or the new dedicated lines. Within the HFQ® Partner Network there will be accredited providers of furnaces, presses and automation to ensure a cost-effective, reliable and capable production solution.

By utilising HFQ® Technology designed parts, manufacturers in the automotive sector can take advantage of the engineering flexibility to use a variety of different grades of aluminium, namely: 5xxx, 6xxxand even ultra-high-strength 7xxx series aluminium. In future, high-recycled content alloys, offering lower cost and major carbon-saving benefits will be compatible with the HFQ® process, which because of its metallurgical characteristics can maintain formability even with high levels of impurities, which would otherwise render the alloy unsuitable. Linked to its inherent recycling benefits, he HFQ® Technology standard also enables partners to create a closed-loop cycle of aluminium within their business, as up to 90% of this metal could be recycled at the end of the product lifecycle.

As a result of this widening application envelope for aluminium enabled by the strength and formability associated with HFQ® Technology, OEMs are, in some cases, even looking at replacing carbon fibre applications with HFQ® Technology components, thereby reducing cost even further and providing other practical benefits associated with aluminium structures.

The HFQ® Technology process

Figure 1



The HFQ® Technology process explained

The first stage is to heat a standard heat-treatable grade of aluminium sheet in a furnace until it reaches its solutionising temperature (c.550°C), depending on the grade of aluminium alloy. From the furnace, via an automated process, the blank is then transferred to a press and formed between a cold punch and die tool.

The tools remain closed for 5 to 10 seconds to allow rapid cooling of the formed part, until the pressing is quenched. For all aluminium grades, quenching freezes the microstructure of the alloy in a supersaturated solid solution state. During the forming process, there is, in effect, virtually no cold-working of the aluminium alloy, thereby eliminating the need for complicated springback compensation in the part design.

Subsequently, should a heat treatable aluminium alloy be used, the part can be artificially aged to further increase the strength of the pressing, thanks to the prior quenching method – taking a little over two hours for aluminium grade AA6082 to achieve peak strength. This is a significant improvement over the nine-hour standard ageing time for this alloy using current hot rolled methods.

The reduction in ageing time is due to the dislocations developed during the forming stage, as they provide nucleation sites for precipitates, which is the mechanism by which the alloy achieves its maximum strength. The final artificial ageing time required to achieve peak strength is therefore dependent on the strain attained during the forming process. The HFQ® Technology thermo-mechanical processing cycle, has been developed to ensure the final microstructure-mechanical property relationship enables full alloy strength, without compromising the desired design elements of the part.

Partial artificial ageing may also be carried out, followed by full ageing after the part has been assembled into the vehicle structure. Full ageing in this scenario, means that HFQ® pressing can take advantage of the heat generated during the paint bake process to achieve the highest strength.

As *Image 1* (below) depicts, full comparisons between HFQ® Technology and cold-rolled forming, using 6xxx-series aluminium for complex deep-draw pressings showed the complete forming of the parts using HFQ® Technology. The same process using cold forming was not achievable and caused splitting of the alloy sheet along the deeper-drawn and tight feature radius sections of the die. These characteristic failures of aluminium at room temperature were noted even during the early stages of forming.

HFQ® Technology's ability to improve formability widens the scope for automotive applications in terms of design freedom, process optimisation and achieving high levels of structural strength and stiffness within component Bill of Materials (BOM) cost budgets (*see Image 1 below*).

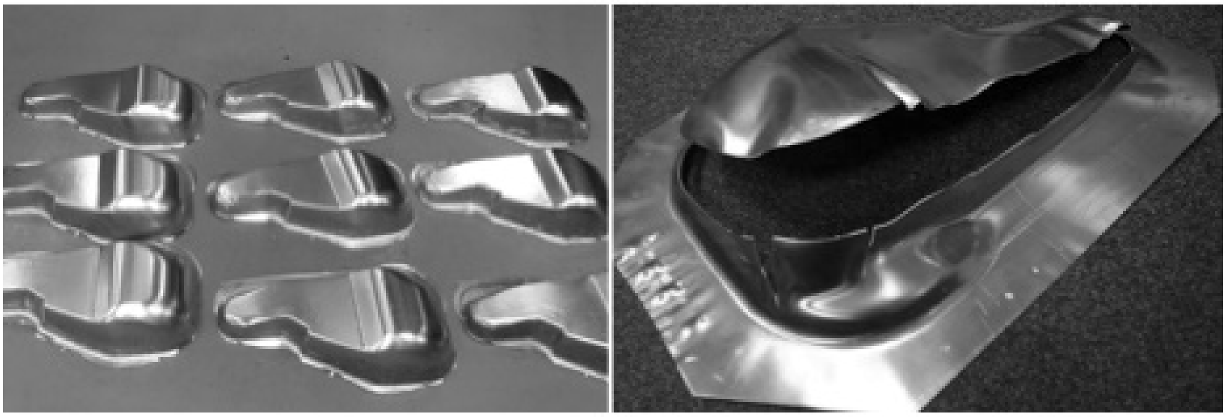


Image 1: *(Left) Selection of successfully pressed deep-drawn rear bulkheads formed using AA6082 T6 aluminium with HFQ® Technology. (Right) Identical material and bulkhead part sheers when pressed at room temperature using conventional cold pressed methods.*

Additionally, HFQ® Technology allows for refinement of existing aluminium structures by offering reductions in material thicknesses, while still maintaining high-strength, as well the flexibility to allow for tailor-welded blanks of varying thicknesses, for weight and material use optimisation.

Harnessing the HFQ® Technology global standard through the HFQ Partner Network

The benefits of joining the HFQ® Partner Network:

- Collaboration to secure additional business opportunities
- Access to technical support for commercialisation
- Promotion via HFQ® Technology brand and accreditation
- Influence in the way HFQ® Technology is developed and marketed
- Reduced time and costs of duplicated development efforts
- Opportunity to collaborate on joint technology development programmes

HFQ® Technology's guiding principles are to establish and advance the technology standards to meet the changing requirements for automotive light-weighting. The HFQ® Technology community and evolving standards will add value to your entire production process and it is supporting automotive light-weighting in the following ways:

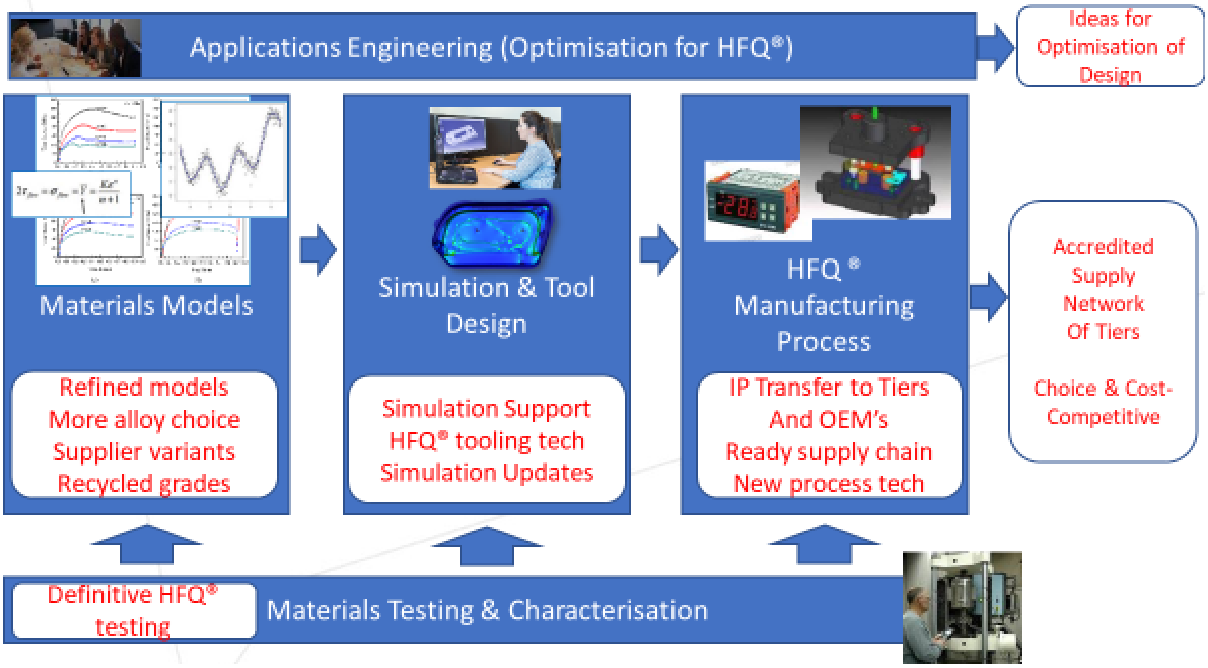


Figure 2: Supporting the application of HFQ® Technology

Businesses applying the HFQ® Technology standard in their production processes will also benefit from access to expert design engineers who are able to develop and prototype parts to meet even the most complex requirements. Through the partnership, HFQ® Technology will support and advise on the correct tooling as well as providing trial runs at its in-house facility before full-scale production. In order to achieve and maintain the world-class standards of HFQ® Technology, full training and development support is provided to your team.

Case Study: Upgrading technology for traditionally formed panels [2]

To deliver the greatest benefit, HFQ® Technology should be adopted at the outset of a design programme. This allows designers to reduce part count and potentially replace conventionally used metallic solutions such as extrusions, castings and low strength pressings with HFQ® stamped alternatives, thereby reducing assembly cost and weight. The following examples aid designers who are planning to use HFQ® Technology to develop high-strength lightweight assemblies and individual parts.

A growing number of automotive, aerospace and rail companies are now using or evaluating HFQ® Technology in order to deliver cost-effective lightweight design solutions for structural parts. A review performed in partnership with Lotus Engineering identified aluminium automotive panels for which HFQ® Technology could deliver light-weighting potential as illustrated in Image 2 [3].

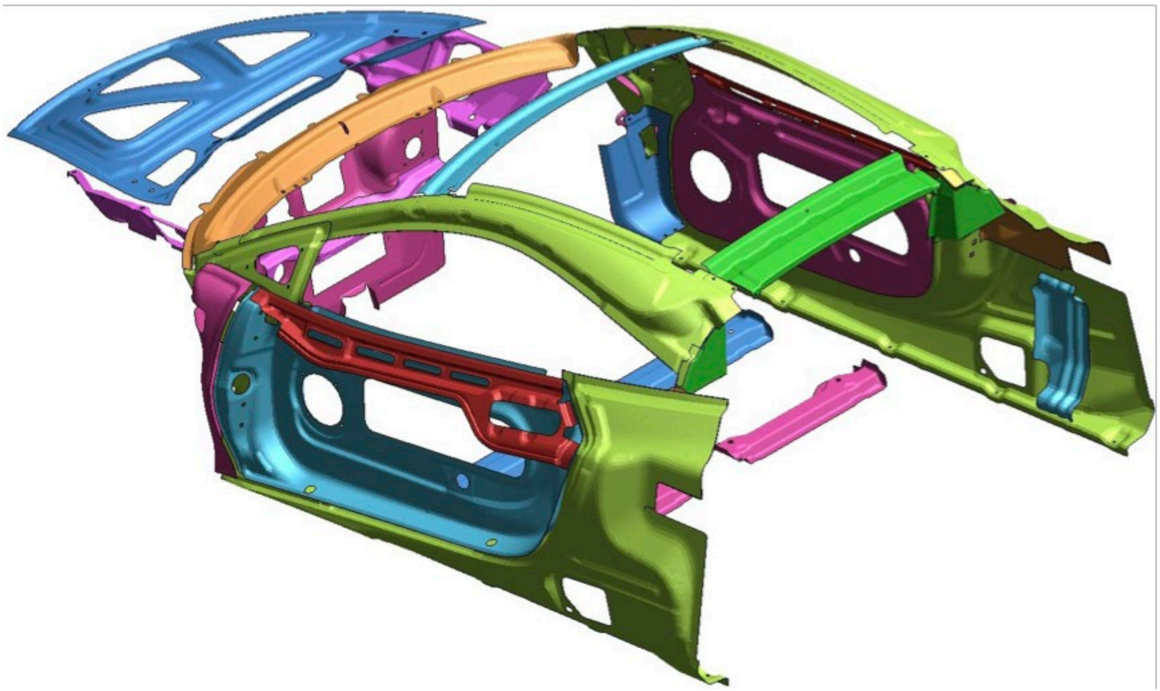


Image 2*: *Examples of components considered for HFQ® forming (reproduced from [3]). Colours used for clarity of individual parts.

<u>Example: Use of HFQ® Technology to delete an A-pillar reinforcing extrusion</u>

A vehicle's A-pillars are integral structural members running both sides of the windscreen and typically extend from below dash level upwards into the roof structure. The A-pillar must support roof crush loads under crash conditions, which impose substantial bending moments on the pillar, therefore the pillars are required to withstand major loads without excessive collapse.

During the design phase, full Finite Element Analysis is performed in order to evaluate the structural performance of the designed pillar. However, when exploring the production route during the vehicle concept phase, a highly simplified method is required to indicate the relative performance of components made to different designs and by different technologies.

In the first example, the structural capabilities of three possible A-pillar cross-section designs are compared. The first considers a two-part A-pillar stamped in AA5754 with a central reinforcing extrusion from alloy AA6082. The second considers an alternative design having the same mechanical strength but using AA6082 HFQ® stamped components and having no additional reinforcing extrusion.

The third considers the use of high strength AA7075 aluminium HFQ® pressings with no central reinforcement. Plastic collapse bending moments were calculated assuming through-section plasticity and do not account for the formation of a plastic hinge. Further work on hardening of the material was not considered. The designs were simplified to exclude the bonding flanges of pressed parts.

In Figure 2 (below) screen shots are presented of the simple spreadsheet used to assess designs. A base geometry representative of a potential design that utilises existing technologies is given in Figure 2a. A revised geometry representative of an HFQ® solution is given in Figure 2b. The bonding flanges of the formed outer are not considered in the assessment and are therefore shown as greyed out in the figures.

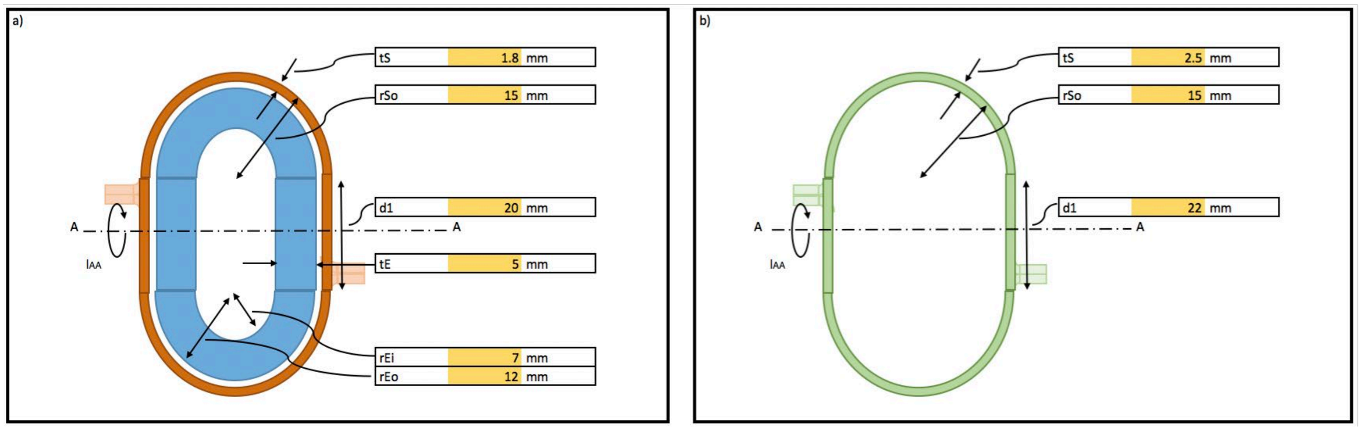


Figure 2a (left) and 2b (right): *Simplified A-pillar cross-sections to identify relative performance of conventional vs HFQ® design solution. Flange details (shown as light horizontal extensions) were not considered in the calculations.*

Table 1. Description of dimension terms referred to in the Figure 2.

Dimension	Description
tS	Thickness of pressed panels
rSo	Outer radius of pressed panels
d1	Straight section length
tE	Extrusion thickness
rEi	Extrusion inner radius
rEo	Extrusion outer radius

Table 2. Assumed material properties referred to in the Figure 2.

Material	Yield (MPa)	Density (Kg/m^3)
AA5754	120	2 660
AA6082	280	2 700
AA7075	450	2 800

Table 3. Dimensions used for each design case

Dimension	Case 1: 5754 skin 6082 extrusion	Case 2: 6082 skin No extrusion	Case 3: 7075 skin No extrusion
tS	1.8mm	3mm	2.5mm
rSo	15mm	18mm	15mm
d1	20mm	23mm	21mm
tE	5mm	-	-
rEi	7mm	-	-
rEo	12mm	-	-

Table 4. Comparison of the plastic collapse load of various design solutions

Case 1: AA5754 skin, AA6082 extrusion	Skin	Skin	Skin
Plastic Collapse Bending Moment (Nmm x 10^6)	0.40	1.61	2.01
Mass per meter length (Kg/m)	0.62	1.35	1.96

Case 2: AA6082 skin	Skin
Plastic Collapse Bending Moment (Nmm x 10^6)	2.10
Mass per meter length (Kg/m)	1.21

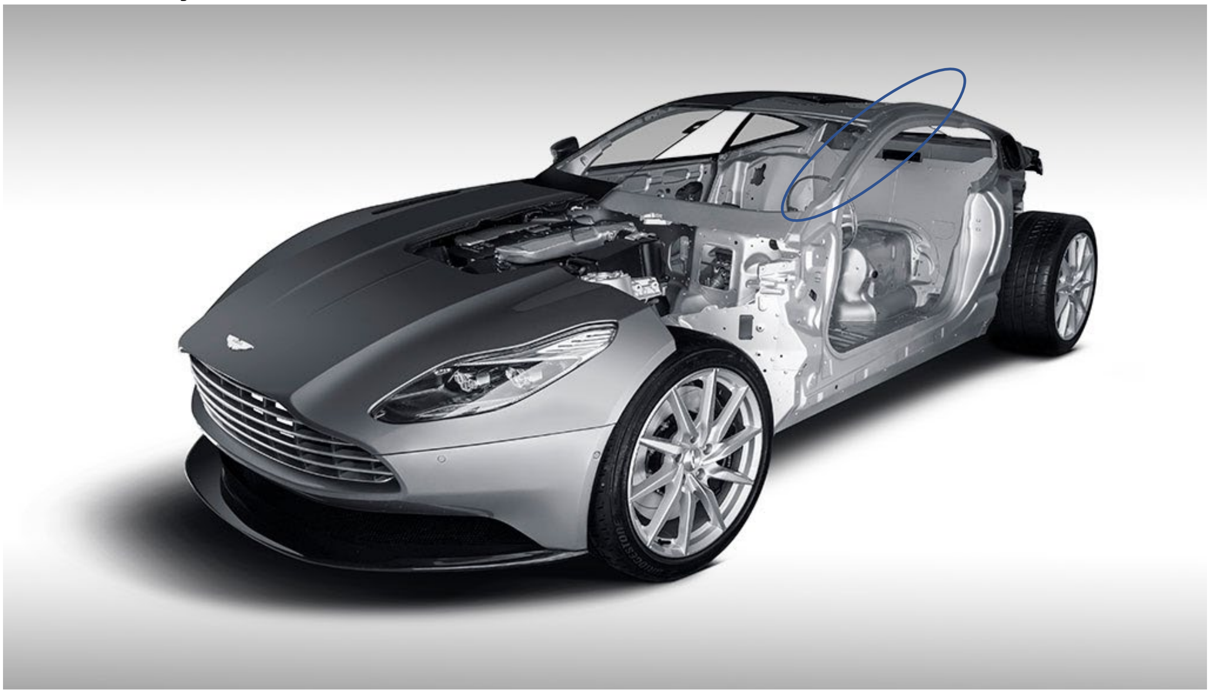
Case 3: AA7075 skin	Skin
Plastic Collapse Bending Moment (Nmm x 10^6)	2.08

Mass per meter length (Kg/m)	0.90

The results indicate that it is entirely feasible to delete the extruded reinforcement component by using HFQ®- formed high-strength aluminium alloys and yet maintain the performance under an applied bending moment.

The overall dimensions of the HFQ® pillars are increased slightly to ensure like-for-like collapse moments. In the case of AA7075 the section width does not increase from the conventional design and the section depth increases by only 1mm, yet the mass per meter length is reduced to less than half. In the case of AA6082 the section width is increased from 30mm to 36mm and the section depth is increased from 50mm to 59mm.

Case Study: Aston Martin DB11 A-Pillar



Aston Martin is one of the first OEMs to realise the benefits of designing parts using HFQ® Technology. The desire to reduce overall weight and part complexity, but enhance torsional rigidity and structural integrity, allowed designers and engineers to work with HFQ® Technology from the earliest phase to design, prototype and manufacture a new A-pillar pressing without compromise.

Aston Martin was able to maintain the desired design language of the DB11 as HFQ® Technology was able to achieve tight radii (1.5T Internal), which reduced the size of the bond flange and single-piece A-pillar for better driver visibility. In addition, HFQ® Technology enabled a complex and deep drawn pillar to be formed in a single draw operation, whilst achieving high levels of strength in roof-crush performance.

The single-draw operation also reduced tooling investment cost, as existing presses were adapted to produce high formability in deep sections of the A-pillar - a result previously not achievable using conventional cold and hot-pressed production methods.

Conclusion

The commercialisation of Hot Form Quench (HFQ® Technology) signifies the start of a new international standard and provides a collaborative roadmap for future light-weighting in the automotive industry.

We have demonstrated in this white paper that the full range of significant advantages can be delivered when HFQ® forming is adopted at the outset of a design programme.

As illustrated by Aston Martin's DB11 use case, HFQ® Technology is already validated on premium vehicles. Complex parts for world-renowned manufacturers are already under evaluation as candidates for HFQ® Technology adoption, as our unique technique has the potential to deliver simpler, stronger structures, to budget.

HFQ® Technology, has an opportunity to catalyse the greater adoption of high strength aluminium alloys, allowing manufacturers to enhance and refine existing structures, while facilitating greater freedom in design and the creation of new body and chassis concepts.

Additionally, through the establishment of HFQ® Technology Partner Network, we are championing continuous innovation through the sharing of best practice between OEMs, Tier 1 suppliers, the full array of other industrial suppliers, research institutes and influential industry bodies.

We believe that this diverse and skilled community will not only benefit from using HFQ® Technology, but collectively drive further innovation in the process itself.

References

[1] Ducker Worldwide: *Aluminium Content in North American Light Vehicles 2016 to 2028* (2016)
[2]. A. Foster, D. Szegda and J. Sellors: *Design Considerations for HFQ® Hot Stamped Aluminium Structural Panels* (2015)
[3] J. Sellors: *Shaping the Future of Aluminium*, Lotus ProActive Magazine, (2013)
[4] M. Raugei, O. El Fakir, L. Wang, J. Lin, D. Morrey, J. *Life cycle assessment of the potential environmental benefits of a novel hot forming process in automotive manufacturing,* Journal of Cleaner Production, Vol. 83, pg80-86 (2014)

Further information

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