MATEC Web of Conferences **21**, 05014 (2015)
DOI: 10.1051/matecconf/20152105014

Design considerations for HFQ® hot stamped aluminium structural panels

Alistair Foster[1,2,a], Damian Szegda[1], and John Sellors[1]

[1] Impression Technologies Ltd., Regus, Central Boulevard, Blythe Valley Business Park, Solihull B90 8AG, UK
[2] Imperial College, Exhibition Road, South Kensington, London SW7 2AZ, UK

Abstract. HFQ is a deep drawing process for alloyed aluminium sheet that can be used to produce complex-stamped forms while maintaining the high-strength of 6xxx and 7xxx alloys. By adopting a strategy to design for HFQ at the platform level, designers can reduce part count (thereby reducing cost and weight), reduce gauge (thereby reducing weight), and improve part packaging. Two simple design examples are given to assist designers in evolving traditionally formed panel designs to HFQ formed solutions. Example features are used to illustrate the effect of geometry, thickness and strength on the final structural component.

1. Introduction

The HFQ forming method is used to stamp complex components from high-strength aluminium alloys. The method combines hot stamping with alloy tempering, resulting in a component of complex geometry and high strength.

When compared with traditional cold stamping of aluminium, HFQ reduces cost and weight and part count and/or enables components to comply with tight packaging constraints. The HFQ manufacturing process has been assessed for its lifecycle environmental benefits and the study reveals that HFQ has whole-life environmental advantages over conventional forming methods [1]. Several publications are concerned with the material response during HFQ forming [2, 3] and literature is also available on the fundamental material evolution during HFQ forming [4, 5]. However, there are few published design examples utilising HFQ and what is available focusses on specific geometries, e.g. [6]. Whilst useful, a more fundamental look at the design advantage of HFQ is of interest to OEMs and design consultancies that wish to design for HFQ manufacture.

To deliver the greatest advantage, HFQ forming 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

[a] Corresponding author: a.foster@impression-technologies.com

HFQ is a registered trademark of Impression Technologies Ltd.

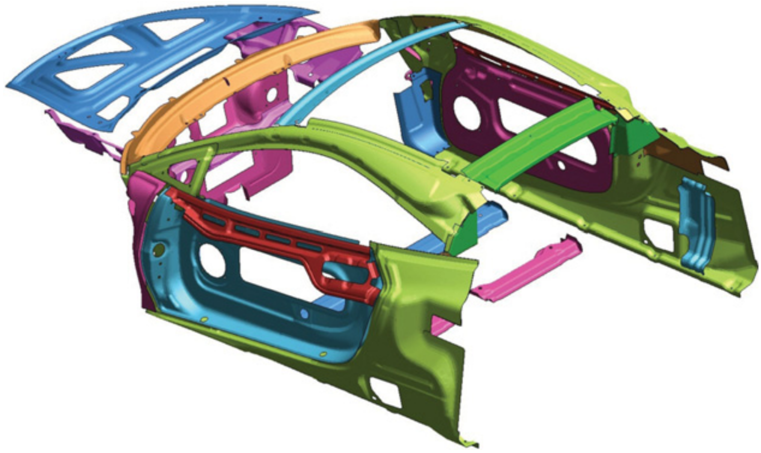

Figure 1. Examples of components considered for HFQ forming (reproduced from [7]). Colours are used for clarity of individual parts.

alternatives, thereby reducing assembly cost and weight. In this paper guidance is presented to aid designers who are planning to use HFQ to develop high-strength lightweight assemblies and individual parts.

2. Application of HFQ

Several automotive, aerospace and rail companies are using or evaluating HFQ forming in order to deliver cost-effective lightweight design solutions for structural parts.

A review performed by Lotus Engineering identified aluminium automotive panels for which HFQ could deliver lightweighting potential as illustrated in Fig. 1 [7].

The review identified panels that would benefit from HFQ forming. These required the use of high strength alloys and high formability to meet structural performance targets.

2.1 Example: Use of HFQ to delete an A-pillar reinforcing extrusion

A-pillars are the structural members that run either side of the windscreen. They typically extend from below dash level upwards into the roof structure. The A-pillar must support roof crush loads under crash conditions, which will impose substantial bending moments on the pillar. The pillar must withstand these crash loads without excessive collapse.

During the design phase full FEA 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.

For A-pillars, a simplistic approach is to calculate and compare the maximum moments that can be withstood before plastic collapse. The resulting moments are then taken as being indicative of the relative effectiveness of the pillar designs. The method requires minimal information – only an approximation of the nominal cross-sections to be compared and strength of the A-pillar materials. Further, the underlying mathematics are simple enough to be coded into a spreadsheet to explore the effect of altering key parameters such as bounding dimensions and sheet thickness.

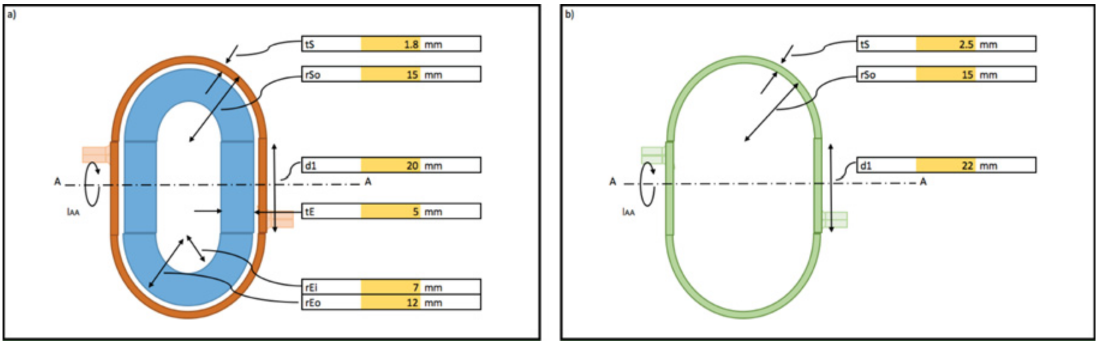

Figure 2. Screen shot of simplified A-pillar cross-sections to identify relative performance of conventional vs. HFQ design solution. Flange details (shown as light horizontal extensions) were not considered in the calculations.

Table 1. Description of dimension terms used in example.

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

The collapse load in bending is referred to as the maximum plastic moment and is calculated using the formula:

$$M_p = \sigma_y Z. \tag{1}$$

In which M_p is the maximum plastic bending moment, σ_y is the yield stress and Z is plastic section modulus.

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 hardening of the material was not considered. The designs were simplified to exclude the bonding flanges of pressed parts.

In Fig. 2 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 Fig. 2a. A revised geometry representative of a HFQ solution is given in Fig. 2b. The bonding flanges of the formed outer are not considered in the assessment and are therefore shown as greyed out in the figures.

In Table 1 a list is given of the various dimensions referred to in the figure.

For each of the two HFQ design solutions, the dimensions and thickness of the pressings were altered in order to match or exceed the plastic collapse moment applied about axis A-A of the conventionally produced cross-section. Table 2 gives the assumed material properties. The dimensions of each design

Table 2. Assumed material properties.

Material	Yield (MPa)	Density (Kg/m³)
AA5754	120	2660
AA6082	280	2700
AA7075	450	2800

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	1.8 mm	3 mm	2.5 mm
rSo	15 mm	18 mm	15 mm
d1	20 mm	23 mm	21 mm
tE	5 mm	–	–
rEi	7 mm	–	–
rEo	12 mm	–	–

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

Case 1: AA5754 skin, AA6082 extrusion	Skin	Extrusion	Total
Plastic Collapse Bending Moment (Nmm)	0.40E+06	1.61E+06	2.01E+06
Mass per meter length (Kg/m)	0.62	1.35	1.96
Case 2: AA6082 skin	**Skin**		
Plastic Collapse Bending Moment (Nmm)	2.10E+06		
Mass per meter length (Kg/m)	1.21		
Case 3: AA7075 skin	**Skin**		
Plastic Collapse Bending Moment (Nmm)	2.08E+06		
Mass per meter length (Kg/m)	0.90		

are given in Table 3, and the resulting calculated plastic collapse load and the mass per unit length of the cross-section are given in Table 4.

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 7075 the section width does not increase from the conventional design and the section depth increases by only 1 mm, yet the mass per meter length is reduced to less than half. In the case of 6082 the section width is increased by 6 mm from 30 to 36 mm and the section depth is increased by 9 mm from 50 to 59 mm.

2.2 Example: Use of HFQ to down-gauge without loss of section stiffness

For many structural components both strength and stiffness must be considered. In comparison of a conventionally pressed aluminium component with a high-strength HFQ panel, simple down-gauging of panel thickness will result in a lighter panel of comparable strength. However, the reduction in panel thickness will reduce stiffness unless the design is modified to compensate.

In the next example, the elastic stiffness of two cross-sections is assessed. The comparison is achieved by calculating the second moment of area for each. The parameter is chosen as, for instance,

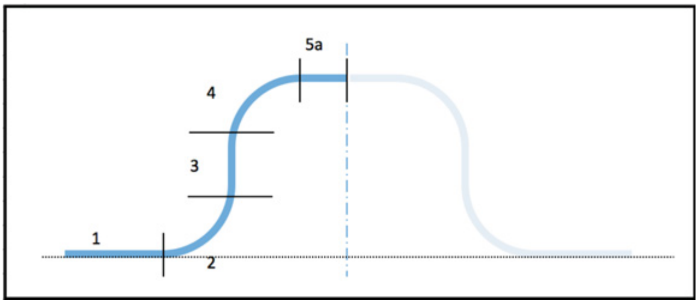

Figure 3. Screen shot of example cross-section of a stiffening feature.

Table 5. Example of downgauging whilst maintaining stiffness.

Dimension (mm)	**Conventional geometry**	**HFQ solution**
Sheet gauge	2	1.6
Feature 1 length	40	40
Feature 2 radius	30	16
Feature 3 length	8	36.4
Feature 4 radius	30	16
Feature 5a length	10	38
Total cross-section height	70	70
Total cross-section width	220	220
2nd moment of area (Nmm)	**534.3E+3**	**549.4E+3**

the curvature of section due to an applied moment is given by:

$$\rho = \frac{EI}{M}. \tag{2}$$

In which ρ is the radius of curvature, E is the elastic modulus, I the second moment of area and M is the applied moment. Thus, if the elastic modulus is constant then the structure's radius of curvature per unit load is proportional to the second moment of area, whereby a large curvature is associated with a greater stiffness.

The simple u-shape cross-section of a stiffening feature chosen for analysis is shown in Fig. 3. The shape is broken up into simple features to assess stiffness of the cross-section when subjected to a bending moment about a horizontal axis.

One possible solution to preserve stiffness when down-gauging would be to increase the length of features 3 and 5a. However, this alone may not be possible due to packaging constraints. By reducing the radii of features 2 and 4, which HFQ enables, to compensate the packaging constraints can be maintained. An example solution is given in Table 5.

In the example provided the packaging constraints have been met with a reduction in sheet thickness and no loss of bending stiffness performance.

3. Conclusions

Two examples are given of how simple analysis tools can be applied to simplified geometries in order to demonstrate the potential use of HFQ forming when considering part count and component design. The HFQ method can be used to deliver lightweight, stiff components from strong alloys thereby giving designers the forming ability they seek for future lightweight structural designs.

References

[1] M. Raugei, O. El Fakir, L. Wang, J. Lin, D. Morrey, J. Cleaner Prod, **83**, 80–86 (2014)
[2] O. El Fakir, L. Wang, D. Balint, J.P. Dear, J. Lin, T.A. Dean, Int J. Mach Tool Manu, **87**, 39–48 (2014)
[3] M. Mohamed, J. Lin, A. Foster, T. Dean, J. Dear, Proc Eng, **81**, 1689–1694 (2014)
[4] M.S. Mohamed, A.D. Foster, J. Lin, D.S. Balint, T.A. Dean, Int J. Mach Tool Manu, **53**, 27–38 (2012)
[5] R.P. Garrett, J. Lin, T.A. Dean, Int J Plasticity, **21**, 1640–1657 (2005)
[6] J. Zhou, B. Wang, J. Lin, L. Fu, Archives Civ Mech Eng, **13**, 401–411 (2013)
[7] J. Sellors, Lotus ProActive Magazine, **50** (2013)