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LoCoLite

An industrial system enabling the use of a patented, lab-proven materials processing technology for Low Cost forming of Lightweight structures for transportation industries

SME-targeted collaborative projects

Publishable Summary

By

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PU	Public	X
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RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Executive Summary

Through the EU FP7 LoCoLite project, an efficient and low cost aluminium Solution-Heat treatment, cold-die Forming & Quenching (HFQ®) mass production system and processing method was developed, using low cost tooling materials with minimal lubrication achieved through tool surface treatments. The work follows on from the HFQ® technique developed and successfully proven in laboratory trials by Prof. Lin and his team at Imperial College London, offering a highly promising manufacturing method to form complex high strength sheet parts for low cost.

Furthermore, supporting infrastructure for designers was developed in the form of an expert system, which provided information on tool design and processing conditions to achieve HFQ® produced components to specification requirements. Moreover, the application of HFQ® for industrial components was be evaluated through the forming of complex shaped demonstrator components for both the automotive and aerospace sectors. As a result of the project, HFQ® produced components have begun being applied on Aston Martin and Lotus Cars in the year 2016 with approximately 9,000 component orders for the year 2017.

The main achievements of the LoCoLite project are summarised below:

- **The Planed objectives of the LoCoLite project** have been fully achieved and more unexpected results have also been obtained.
- **The worlds 1st HFQ® dedicated production line** has been built by APT and established at ITL for commercial production. This was not planned in the project due to limited funding. However, with multi-million Euros private investment for the technology, the production line is in operation from June 2016. Further details can be found at: http://www.ismr.co.uk/news/hfq-aluminium-forming-line.html
- **A range of real-size complex-shaped high strength lightweight panel components formed.** Automotive and aerospace full-scale demonstrator components, such as the CRF cross-beam and B-pillar, Lotus Door Inner and Aircraft Armrest components, have been formed. The components cannot be formed using existing stamping technologies apart from HFQ®. This provides the confidence for private investors to provide funding on the world 1st production system.
- **A new Spin-Off established.** Two partners, PAB and ITL, have jointly established a new SME, CIPCO, which is specifically for HFQ® production.
- **HFQ® parts for production.** Many components have been formed for real car models in Aston Martin and Lotus, which are on road in 2016. An example can be seen from:

https://www.gov.uk/government/case-studies/new-aston-martin-db11-features-uk-firms-low-carbon-innovation. It has been demonstrated that by the use of the HFQ® technique for replacing steel body and chassis structures by high strength aluminium, the weight reduction could be 40-53%, which results in fuel saving of 20-25%, and, CO2 emission reduction by 28.6-35%.

- **Further exploitation.** The HFQ® Club, consists of the whole HFQ® technology and research supply chain organisations, has been initiated for further exploitation, which ensures the sustainability of the exploitation. This is benefit driven for individual members, i.e. PAB has received significant orders in 2016 and has doubled in the following 2 years.
- **Increase participation of women in innovation.** Approximately 20% of consortium staff were women.

2. Summary description of project context and objectives

Rapidly fluctuating fuel prices, stringent legislative requirements as well as consumer demand for environmentally friendly technologies has resulted in manufacturers of vehicles and aircraft to pursue technologies that reduce fuel consumption and carbon footprint during the entire life cycle of the product, including production and the operational life. In this regard, considerable effort has been made by industry to address these issues, particularly in the EU, by improving propulsion technologies and structural component weight. However, research studies have found that [1]: (i) there is no single vehicle technology strategy that can cost-effectively achieve the 50+ miles-per-gallon (MPG) fuel economy target without significant weight reduction; (ii) weight reduction can be achieved by materials substitution - such as switching from steel to low-weight, high-strength aluminum - to avoid less desirable downsizing of vehicles; and (iii) weight reduction with aluminum is a cost-effective complement to maximize the benefits of all other fuel economy improvement technologies.

Therefore, the most effective method to achieve weight and emission reduction targets is to reduce the weight of vehicles. However automobile manufacturers have encountered prohibitively high material and production costs in the use of some lightweight materials such as magnesium alloys and composites, which has limited their application to racing cars, sports cars and luxury super-cars. For conventional passenger vehicles, the cost-weight balance is in favour of the use of aluminium alloys. Low cost automotive aluminium alloys, such as 6xxx and 5xxx series, have been developed and produced in large quantities, which are being used for automotive body panels, but these currently produced panels are of lower strength and simpler shape complexity than conventional steel ones they have replaced.

To this end, a patented technology named Solution-Heat treatment, cold-die Forming & Quenching (HFQ), has been developed and proven with successful laboratory trials, by Prof. Lin and his team at Imperial College London, as well as with full scale production components as part of the LoCoLite project. The results of the project have demonstrated that the process is a highly promising manufacturing method to form complex high strength aluminium sheet parts at relatively low cost.

The overall aim of the LoCoLite project has been to develop an efficient and low cost aluminium HFQ mass production system, using low cost tooling materials and minimal lubrication, achieved through tool surface treatment. In addition, supporting infrastructure to aid in design and development of components has been developed in the form of an expert system, which enables a designer to derive the appropriate tooling geometry and process conditions to achieve successfully formed HFQ components. Finally, the post-form performance of the produced components has been optimised through the use of tailored heat treatments in order to achieve the required mechanical properties.

The Specific Objectives (SO) of the LoCoLite project as follows:

SO1. Further develop/optimise the HFQ material processing route from its current post-laboratory state, so that (i) aluminium sheets can be processed for high strength panel parts from virgin metal at low cost and, (ii) recycled aluminum (aluminium alloy can be recycled very cheaply) can be used to reduce the cost further.

SO2. Develop a low-cost, highly efficient HFQ mass production system, for high-strength aluminum alloy panel production. This includes reducing energy consumption and design of low cost tooling, handling and automatic control facilities.

SO3. Create a redesign system for HFQ aluminium to enable (i) existing steel panels and structures to be replaced by aluminum stampings, with minimum redesign, to meet the same structural specifications, and, (ii) reduce the number of parts (component consolidation) that have to be used in current aluminum panel structures with the consideration of life-cycle and efficient recycling.

SO4. Enable car body and chassis structures to be produced in aluminum alloy with weight saving of over 40% for Class D & C and above segment vehicles (which are currently made of steel). Thus, 50% of cars will be made with aluminum body and chassis structures. The fuel saving, in car usage will be on average up to 23%.

SO5. Develop an innovative integrated exploitation strategy for HFQ aluminium, so that the materials supply chain, design technology supply chain, material processing and manufacturing technology supply chains can be effectively integrated, and, the positive impact on industry quickly maximised.

SO6. Increase the global competitiveness in EU transportation industries by realising the full potential of the patented HFQ materials processing technology for manufacturing lightweight structures. Over 1,700 jobs will be created in 8 years with growth of new businesses in vehicle design.

The Specific Objectives of the LoCoLite project and the achievements over the course of the project are summarised in a measurable and verifiable form together with their criteria for assessment in Table 2.1.

Table 2.1 Specific Objectives, milestones, criteria for assessment

Specific Objectives	**Indication of achievement by Milestone***	**Criteria for assessment**
SO1	Month 10 / Milestone M1.2 & Month 30 / Milestone M6.3 & Month 36 / Milestone M6.4	The new materials processing routes have been defined and the results have been validated from industrial scale production of demonstrator parts. Assessed according to (i) Cost reduction of material blanks, (ii) Ageing process efficiency evaluation, (iii) Comparison of mechanical properties resulting from the new process with those from traditional processes, and, (iv) Cost analysis.
SO2	Month 12 / Milestone M1.4 & Month 18 / Milestones M2.1 & M2.3 & Month 24 / Milestone 5.2	Creation of low cost and efficient HFQ production system. The assessment includes (i) Innovative tooling technologies enabling HFQ of aluminium to be performed without lubricant – the cost and efficiency are compared with current tooling and forming requirements, (ii) Detailed calculation of cost reduction and efficiency increment, compared with current tooling, heating and control systems.
SO3	Month 12 / Milestone M3.2 & Month 18 /	HFQ design strategies have been developed for individual applications and tested on demonstrator part design and forming – success/assessed by (i) OEM end users, (ii)

	Milestone M3.3	Tier-1 end users. Other potential applications have also been identified.
SOs 4, 5 & 6	Month 30 / Milestone M6.3 & Month 24 / Milestone M7.2, & Month 36 / Milestones M7.3, M7.4 & M7.5	An assessment of the quality and costs of HFQ formed parts has been performed based on the use of the production system developed in the project. Detailed assessment includes (i) Cost analysis for different applications; (ii) Quality of formed parts and weight reduction achieved; (iii) Environmental impact including fuel saving and CO2 reduction; (iv) Material cost and cost reduction through using recycled aluminium; (v) Further market size expansion for other applications; (vi) Efficiency of running the production and supporting systems; (vii) A business plan for further commercialisation and supported by defined training and dissemination programs.

3. A description of the main S&T results/foregrounds

The primary result of the project was the development of a low-cost production system capable of producing life-size industry components through the HFQ process. This production line, which is the first of its kind worldwide, has been completed as part of a LoCoLite spin-off company called CIPCO based in Coventry in the UK. In addition, the project has enabled material testing and theories to be established to better predict HFQ processing conditions. In particular the project has provided significant developments in the modelling of material behaviour and the performance of tool coatings exposed to HFQ forming conditions. These established models have complemented and have been integrated with existing commercial FE software to enhance the capabilities of these software packages. A knowledge based system developed in the project, and used in conjunction with FE software has enabled greater designer flexibility as well as reduced training time for new engineers as they become familiar with the HFQ process. All the planned tasks for the work packages of the Annex I were achieved during the project. The detailed achievements of each work package are outlined in the following sections.

3.1 Work Package 1: Industry needs, quality control and standards

The work-plan of WP 1 was subdivided into 4 key tasks as outlined below.

- Market Studies and industry specifications for demonstration parts
- Low Cost materials processing route definition
- Hardware and software specifications for HFQ production system
- Recommendation of Standards and Regulations for HFQ

Market Studies and industry specifications for demonstration parts

For this task, market studies were performed for the automotive and aerospace industries. For the automotive sector, the main area of investigation was the use of HFQ® to reduce vehicle emissions through lightweighting. For aerospace, cost reduction, improved material utilisation and accuracy were sought. The environmental impact of HFQ® was captured through a lifecycle analysis study reported in D1.7 were an interactive mathematical model was presented to allow manufacturers to evaluate the lifecycle impact of HFQ® and compare to other processes.

To understand industry specifications, process parameters were determined based on mechanical properties of materials such as their yield-locus behaviour, strain rate sensitivity, and temperature effects on plasticity. Press requirements between 630-1000tons were also examined in order to form components as well as minimize the quenching time under high applied pressure. Technical data of existing presses was investigated in order to ensure that the available tooling was capable of forming life-size automotive and aerospace components. In order to achieve the rapid work-piece quenching required to achieve a high performance HFQ cooling methods, including tooling channels machined into the tool were investigated including the specifications of flow rate, and water pressure.

Tool materials such as cast iron materials were compared to traditional tool materials to identify advantages and disadvantages in substituting them. It has been found that although their overall performance is lower, the surfaces of cast iron tools that contact work-pieces can be substantially improved to cope with operating conditions through surface treatments, such as nitriding, nitro-carburizing and other coatings (CVD and PVD). Analysis of these coatings to determine thickness requirements and layering approaches has been undertaken.

Low Cost materials processing route definition

The HFQ process was subdivided into its constituent stages and each one analysed in turn to identify the most cost effective method to achieve a particular part. Mechanical properties of the grades AA5754, 6082 and 7075 were investigated and presented in order to determine appropriate solution heat treatment (SHT) and ageing temperatures and their respective times to successfully HFQ them.

For AA6082 this occurs in the window between 500-525oC. However, the time required to maintain this temperature varies depending on the temper in which the material was supplied, for example T6 temper requires only 5 minutes whereas O temper requires approximately 30 minutes. Transferring a work-piece to press from furnace has been investigated as the transfer time must be very short in order to temperature loss the material. A transfer time of 10 seconds is required from furnace to alignment on tools. It is recommended that some form of alignment mechanism is used in order to ensure repeatability of the forming. Forming and quenching is a combined process where the compression between the punch and die forms the component into shape and simultaneously rapidly cools the material (approx. 100oC/s) in order to produce a super-saturated solid solution material without precipitate nucleation and growth.

Finally, having formed a component, the material must be brought to maximum strength which is the T6 condition. The time criteria for low cost production by HFQ as a high volume production process offering significant savings in terms of material cost and time are: use of low cost hot rolled 6082-O temper material or cold rolled 6082 H18 combined with the reduction of SHT time to 1 minute, followed by rapid forming and quenching times in the order of seconds and a final ageing process under 1 hour. This would allow the process to be highly competitive in high volume production.

Hardware and software specifications for HFQ production system

A methodical approach to review and rank the various available technologies for heating, handling, and pressing the aluminium sheet was introduced in D1.4. The results of the study were necessarily biased to the technologies available in a commercial or near-commercial state. However, during the research and review process the benefits of future technologies can be seen. The final recommendations were similar to those used on hot-formed boron steel lines; a convection oven for solutionising, followed by linear handling of the blank to a hydraulic press. This was the basis of the first commercial HFQ® line later installed at Impression Technologies Ltd.

During the task, it was realised that the heating method for Aluminium must overcome challenges associated with the high emissivity of sheet. From the review, resistive heating or induction heating showed good potential to reduce blank heating times and the possibility was raised of combining these with a conventional oven to ensure temperature uniformity.

Recommendation of Standards and Regulations for HFQ

The focus of this work was identifying the health and safety issues associated with the HFQ process, environmental considerations as well as quality assurance for parts produced using the process. The

HFQ process is an elevated temperature process with working temperatures approaching 500°C. Regarding health and safety issues, existing safety regulations pertaining fire safety, fire prevention, electrical safety standards and Material Safety Data Sheets (MSDS) for lubricants and aluminium alloys used are sufficient to ensure safe operation of the HFQ press lines. Environmental considerations surrounding the process are associated with the disposal of non-metallic waste material, waste lubricant and scrap aluminium. In particular the disposal of washing water containing lubricant material should be treated with appropriate filters for the removal of graphite. Scrap aluminium material is readily recyclable and best practice states that the material should be arranged by material grade in order to avoid contamination.

Quality assurance has been evaluated through non-destructive test methods (NDT) such as hardness tests for each part produced as well as randomly selected destructive tests (tensile tests) in order to ensure consistency in mechanical performance of the produced parts. Quality Assurance has been achieved through supporting Process Failure Mode Effect Analysis (pFMEA) documents.

3.2 Work Package 2: New tool and machinery technologies

The work-plan of WP 2 was subdivided into 3 key tasks as outlined below.

- Develop low cost low friction coated stamping tools for HFQ aluminium, to be used without lubricant
- Develop energy efficient heating facilities for HFQ aluminium
- Develop low cost effective press control systems and adapt the current hydraulic presses for HFQ aluminium

Develop low cost low friction coated stamping tools for HFQ aluminium, to be used without lubricant

The objective of Task 2.1 during the LoCoLite project has been focused on the achievement of improved stamping tools with an extended life in service and the reduction of lubricants.

On the one hand, a study of the base material was developed in order to achieve the best mechanical properties and not increasing the cost of the tooling. In that sense, important progress has been made thanks to the development of a customized cast iron material for HFQ (Hot Forming Quench). The special processing of this alloy, consisting on the filling of the pores using nano-graphite, provides improved tribological properties – low coefficient of friction. This helps to reduce lubrication during stamping processes. On the other hand, different surface engineering strategies have been studied to improve the mechanical properties of the tooling. It was aimed to increase the wear resistance, reduce friction coefficient and avoid aluminium adhesion to the surface of the tool. Different strategies were implemented to achieve the maximum performance of the tribological systems. Thermochemical treatments (plasma nitriding and nitrocarburising), electrochemical treatments, PVD coatings and a combination of thermochemical and PVD processes have been studied as shown on Table 3.2.1.

Table 3.2.1. List of treatments studied in LoCoLite project

PVD Coatings	Thermochemical treatments	Others
DLC (1) – *CrN*	DC Plasma Nitriding *(ASPN)*	Silver alloyed G3500
DLC (2) – *AlTiN*	DC Plasma Nitrocarburising *(PNC)*	NiBN
DLC (3) – *low Si*	Plasma Nitriding *(Arc activated)*	NiBN – *Plasma Nitrided*
DLC (4) – *high Si*		NiBN – *Post Hardened*
WC:C (1) – *mono*		
WC:C (2) – *multi*		
Mo (1) – *thin*		
Mo (2) – *thick*		
CrCN		

Among these treatments, it has been stated that nitrocarburising or plasma nitriding treatments provide beneficial properties to the material regarding hardness and wear resistance, whereas carbonaceous coatings (WC:C and DLC) lead to a significant reduction of the friction coefficient and the need of lubrication, as was observed through different lab tests. Comparing the tribological behaviour of the grey cast and the developed coatings, a reduction of the COF from 0.54 to 0.15 (DLC) and 0.27 (WC:C) was achieved at 450 ºC using Aluminium counterparts. The adhesion rate on Al significantly decreased for WC:C coating whereas DLC layers provided better wear resistance. The combination of nitro-carburising and PVD coatings also enhanced the adhesion of the layers.

The use of carbonaceous coatings was successful in U-shape bending tests, in which a reduction of the lubrication to only 20% of the original lubricant was achieved thanks to WC:C layers. HFQ field trials were carried out after the implementation of surface engineering treatments on the armrest tooling. A nitro-carburising treatment followed by a polishing process (up to 20 nm Ra) coated with DLC (CrN based) was trialled, as it is able to provide low coefficient of friction and significant wear resistance. Field trials demonstrated relatively good performance of the tooling in terms of lubrication. A reduction of the amount of lubrication up to 43% was achieved without influencing the quality of the stamped parts.

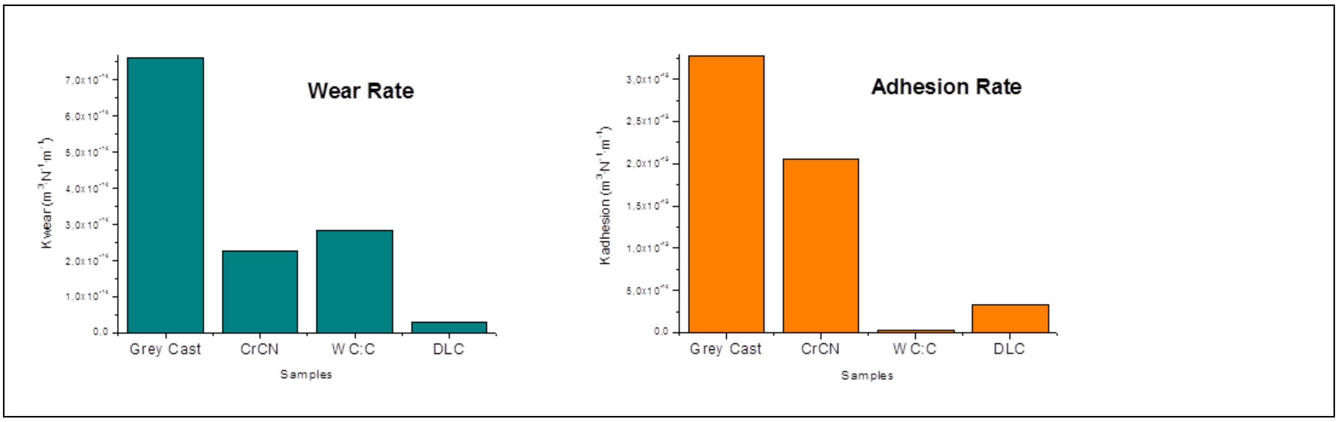


Figure 3.2.1. Wear rate (left) and Al adhesion rate (right) for the grey cast samples used as reference and several carbonaceous coatings.

Develop energy efficient heating facilities for HFQ aluminium.

The technical requirements and the study of a conceptual design of an induction heating oven for the HFQ process was developed in this task. Different aspects were considered: (i) Heated materials: 6xxx & 7xxx Al alloys, flexible for other metals (such as steels), (ii) Dimensions and shapes: 600×400×(1-4) mm, irregular shapes, (iii) Temperature & Heating rate: Heated from 20°C to 550°C at a heating rate > 50°C/s, soaked for 1-60 min. Components of facilities have the temperature resistance of 900°C; Uniform temperature distribution, over-heating/under-heating should be avoided, (iv) Available integration with the automatized transfer unit and main control unit: The heated blank can be quickly withdrawn from the facilities; Interface between the facilities and the main control unit. The study envisaged a two-stage heating process: Induction heating for the high rate heating (induction oven) and indirect resistance heating for the long time soaking (electric furnace).

Transverse flux induction heating (TFH) technology was selected for the design of heating Al alloys sheets, due to its high power density & energy efficiency, compared with longitudinal flux induction heating (LFH).

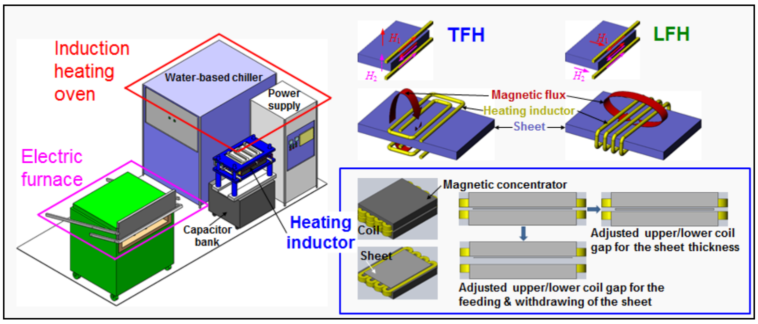


Figure 3.2.2. Conceptual design of the induction heating oven

On the other hand, the study of automotive coatings was addressed. It was concluded that a multilayer structure was required to fulfil the desired properties.

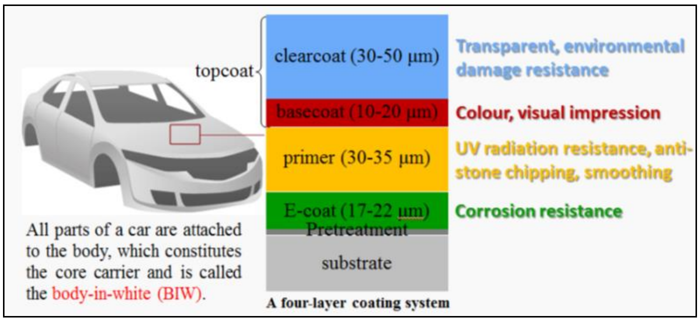


Figure 3.2.3. Multilayer structure of the automotive painting

Two painting methods were studied: (i) cathodic electro deposition (The dip tank is anode, the car body is a cathode. Coating particles with a positive charge migrate toward the car body with the aid of an electric current and are deposited) and (ii) spray (Paint is applied under the necessary conditions of temperature and humidity in the booth using various spray robots). Considering bake hardening effects when the paintings are applied, pre-treatment of the parts were applied to avoid/reverse clusters formation in Al alloys and to provide secondary phase nuclei. It can be highlighted that HFQ (solution heat treatment, forming & in-die quenching) involves the treatments of resolution and pre-strain, which have positive effects on the bake hardening.

Develop low cost effective press control systems and adapt the current hydraulic presses for HFQ aluminium.

The Production system design specifications for the application HFQ process in hot stamping of Al-alloy blanks were defined in D1.4 which specified the hardware and software for the HFQ production system. Having identified the system specification, a market search for the key equipment suppliers as well as the cost of a typical production system were undertaken. As part of this study, fast heating and cooling system design was conducted, requiring the development of energy efficient heating facilities such as induction heating and spray cooling. Modifications to the press control system were made in order to be adaptable to HFQ technology. This reduced the industrial cost of adoption of HFQ as existing presses could be retrofitted and upgraded to utilise HFQ technology.

The handling Press Control System Design, Prototype and Test Results was conducted in T2.3 under WP2, where the task involved the integration of the results in WP1, WP2 and WP5 in a production-line system control design based on the results from the Tasks 1.3, 2.2, 5.1, 2.5 and 5.2 as well as the existing designs at AP&T. The blank handling device design and evaluation was undertaken and is reported in D5.1 which outlines the customisations made to the handling device in order to minimize heat loss from the aluminium sheet during transportation from the furnace and positioning on the tool. Finally, the overall production system design was presented in D5.2 and conducted in T5.2 under WP5. The objective was to build a suitable HFQ production-line system with key facilities available. The model of the Production System Development has been presented in D5.3.

3.3 Work Package 3: Innovative part design methodology for HFQ

The work-plan of WP 3 was subdivided into 3 key tasks as outlined below.

- Design methodology for HFQ aluminium
- Automotive panel part design
- Panel part design for aerospace applications

Design methodology for HFQ aluminium

To design components for HFQ, three aspects need to be considered: (i) to convert existing steel parts to aluminium whilst minimising redesign, (ii) consolidate current aluminium panels, to minimise joining and assembly cost and (iii) to design new and original parts with HFQ technology. In order to design for HFQ, the following steps typically need to be followed: (i) part geometry requirement, (ii) material characterisation, (iii) forming simulation, (iv) prototype testing and (v) property evaluation. In many ways the design of HFQ components follows a similar procedure to that of cold-formed components. Iterations of forming simulations and geometry refinement is used to highlight potential problem areas and adapt the design to improve the final part, ensuring unacceptable thinning, wrinkling and tearing are avoided. However, for HFQ, the simulations also must be optimised for speed and temperature. Moreover, as a mass production process, the consideration of HFQ as a production method should be chosen should the following criteria be required: (i) cost effectiveness, (ii) mechanical strength, (iii) fatigue limit, (iv) crash worthiness, (v) minimisation of joining connections, (vi) high volume. For low volume production, alternative manufacturing techniques may be preferred due to the reduced set-up and tooling costs.

Automotive panel part design

The key priority for the automotive industry is to reduce the number of aluminium panel assemblies and consolidate multiple components into a single pressing. The achievement of this significantly decreases manufacturing costs and assembly time. Furthermore, the automotive industry is willing to redesign existing components in order to facilitate this. In addition, the automotive sector has been investigating ways to replace low performance 5xxx alloys with higher performance 6xxx alloys in which the HFQ can successfully form. In addition, the HFQ process is suitable for the production of automotive subassemblies, providing benefits in terms of shape complexity (complex shape with high deep drawing in one single step), overall part reduction (elimination of assembly steps) and definitively, weight reduction. Of particular importance for the automotive industry, the application of HFQ in mass vehicle production must meet the following criteria: (i) Cost efficiency - must allow forming of lightweight materials currently not possible, (ii) Easy to fabricate - the production process must minimize labor intensity and costs, (iii) Process to be easily adaptable to utilize existing machinery, (iv) Repeatable production accuracy - the produced components must be repeatable and spring-back minimized, (v) Good surface finish post forming - the surface quality of the produced components is a priority, especially for outer skin panels, (vi) Minimize tooling design time - the HFQ process must not require extensive tool design time and knowledge when compared to existing forming methods.

Panel part design for aerospace applications

The requirement for aircraft component production is largely the same as the automotive requirements described above with the addition of the following criteria: (i) produce from higher performance alloys such as 7xxx and 2xxx, (ii) offset the advantages of CFRP materials in some structures, and (iii) meet much more stringent safety requirements such as FAA.

3.4 Work Package 4: Modelling and KBES for HFQ optimisation

The work-plan of WP 4 was subdivided into 5 key tasks as outlined below.

- The generation of materials data for HFQ materials modelling,
- The creation of materials models and materials visco-plastic damage constitutive equations.
- The development of a FE (Finite Elements) modelling system for HFQ.
- The development of a KBES (Knowledge Based Engineering System) to support the design of tools and processes for HFQ.
- The validation of the FE modelling results towards HFQ experimental trials.

Materials data generation & materials models creation

A set of dislocation-based viscoplastic damage constitutive equations was defined, which incorporate physical behavioural parameters for aluminium alloys under HFQ conditions. The unified theory has been used for the development of the model consisting of multiple evolutionary equations, through which the evolution rates of state variables, such as plastic strain, normalized dislocation density, and damage were modelled. It enables the visco-plastic flow (including strain hardening and strain rate hardening kinetics), ductility, and formability of the material to be predicted. The material constants within the equations were determined from a range of experimental data. The data was obtained through visco-plastic tests and forming limit tests within a range of temperatures and strain rates expected to be encountered during the forming process. AA6082, which is the alloy most favoured for automotive body structures, was chosen for testing and determination of the material model. The tests included: Viscoplastic tests on aluminium alloy AA6082 under HFQ conditions, forming limit tests on AA6082 under HFQ conditions, fast SHT studies on AA6082 and Fast aging studies on AA6082. In the next figures examples of experimental data and respective computed curves from the created models for the AA6082 alloy are given, for different strain rates and temperatures. Also viscoplastic damage constitutive equations for AA6082 are given, which were determined from the viscoplastic tensile results and photos of the equipment used (chamber of the thermo-mechanical simulator). The relative deliverable with analytical information for the above materials modelling results is deliverable D4.1 (A set of determined visco-plastic damage constitutive equations for HFQ aluminium).

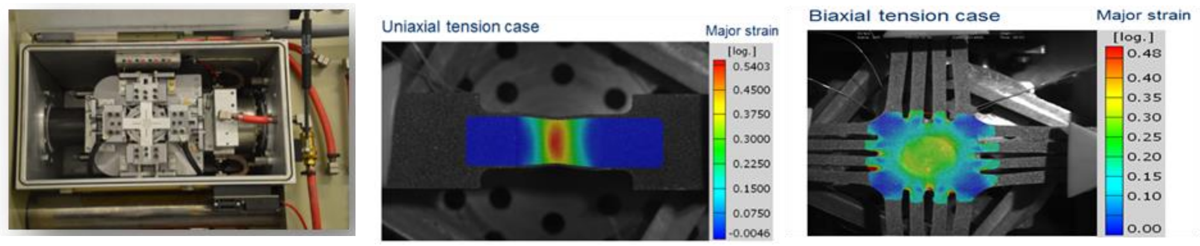


Figure 3.4.1. Test rig is set in GLEEBLE thermo-mechanical simulator.

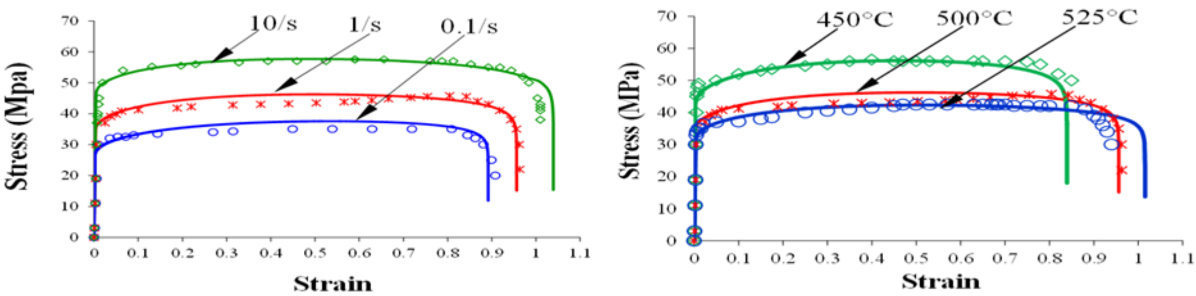


Figure 3.4.2. Comparison of computed (solid curves) and experimental (symbols) stress–strain relationships for AA6082 alloy

$$\dot{\varepsilon}_p = \left(\frac{\sigma/(1-\omega) - R - k}{K} \right)^n \qquad K = K_0 \exp(Q_K / R_g T) \qquad k = k_0 \exp(Q_k / R_g T)$$

$$\dot{R} = 0.5 B \bar{\rho}^{-0.5} \dot{\bar{\rho}} \qquad B = B_0 \exp(Q_B / R_g T) \qquad E = E_0 \exp(Q_E / R_g T)$$

$$\dot{\bar{\rho}} = A(1-\bar{\rho})|\dot{\varepsilon}_p| - C\bar{\rho}^{n_2} \qquad C = C_0 \exp(-Q_C / R_g T) \qquad \eta_1 = \eta_{1_0} \exp(Q_{\eta_1} / R_g T)$$

$$\dot{\omega} = \frac{\eta_1 . \sigma^{\gamma}}{(1-\omega)^{\eta_3}} (\dot{\varepsilon}_p)^{\eta_2} \qquad \eta_2 = \eta_{2_0} \exp(Q_{\eta_2} / R_g T) \qquad A = A_0 \exp(-Q_A / R_g T)$$

$$n = n_0 \exp(Q_n / R_g T)$$

$$\sigma = E(1-\omega)(\varepsilon - \varepsilon_p)$$

K_0 (MPa)	0.702	A_0 (-)	8.139	Q_{η_1}	12030
k_0 (MPa)	2.518	n_0 (-)	0.6451	Q_{η_2}	953
B_0 (MPa)	0.7222	Q_K	22940	Q_A	6411
C_0 (s-1)	102567	Q_k	8857	Q_n	14325
E_0 (MPa)	8.855	Q_B	19489	η_3	17
η_{1_0} (-)	0.00899	Q_C	128828	n_2	1.8
η_{2_0} (-)	0.8362	Q_E	45766	γ	0

Figure 3.4.3. Visco-plastic damage constitutive equations for HFQ AA6082

FE modelling system for HFQ

The determined material models and CDM (Continuum Damage Mechanics) models for HFQ aluminium of Deliverable D4.1 were integrated with the commercial FE code PAM-STAMP of ESI, via user defined subroutines which were included in the PAMSTAMP software code, for the creation of models of the HFQ process. This software provides reliable solutions for HFQ to support the design and manufacture of complex parts from aluminium alloys sheets. Among others, the main output results of the PAM-STAMP FE Element models for HFQ concern thickness and thinning predictions for shell elements of the deformable blank, strains and formability estimations, Tooling/Blank interactions, etc. In the following figures, examples of modelling results of two of the HFQ demonstrator parts are given:

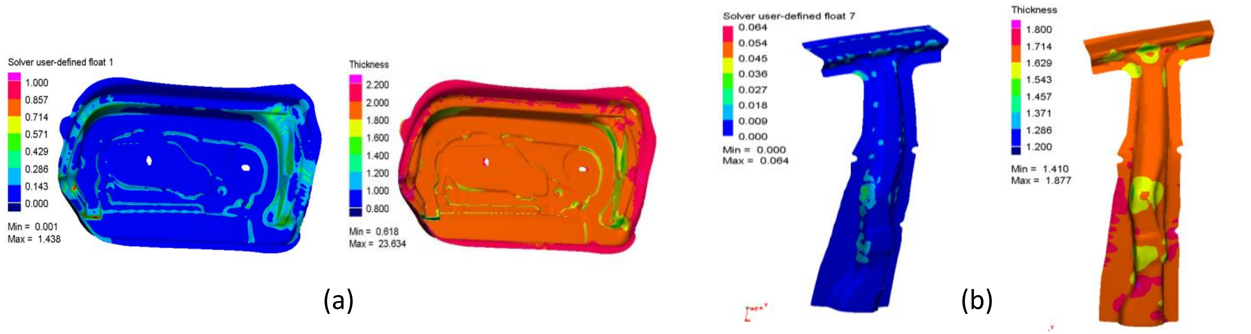


Figure 3.4.4. Plastic Strain modelling example (left) and thickness prediction example (right) for (a) the inner door and (b) B-pillar part

Development of a KBES (Knowledge Based Engineering System) to support the design of tools and processes for HFQ.

A KBES software (Knowledge Based Engineering System) has been developed consisting of 2 modules.

The **KBES Windows module,** which is integrated with the SOLIDWORKS 2015 CAD system using the SOLIDWORKS API (Application Program Interface) and can create basic 3D geometries of the forming tools that correspond to the geometry of a specific product. Besides SOLIDWORKS format, the design outcomes can be exported also in IGES and STEP formats, which can be imported in the PAM-STAMP FE (Finite Elements) modelling system for HFQ (Deliverable D4.2).

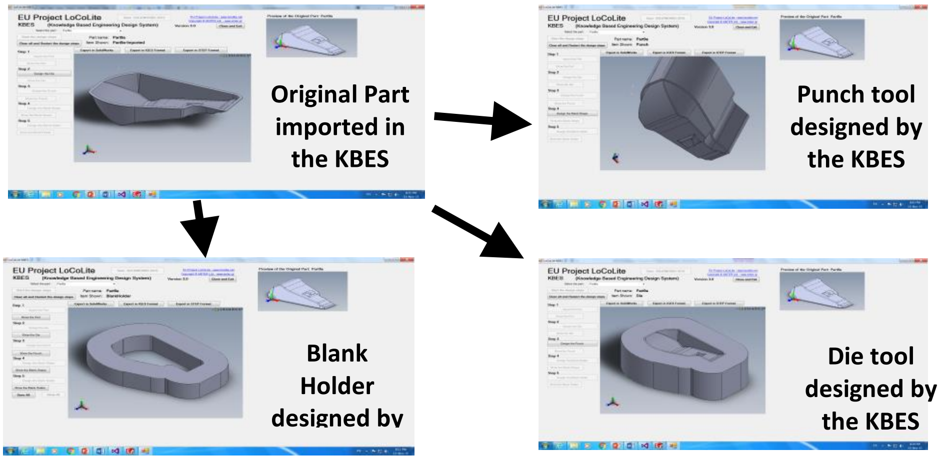


Figure 3.4.5. Examples of design outcomes of the KBES Windows module.

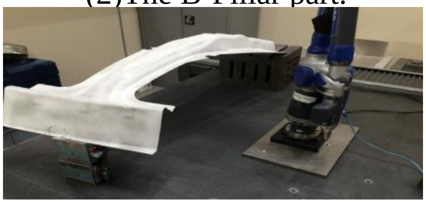
The **KBES Web module**, which can support estimations for detailed adjustments and refinements of tools geometrical details in relation with processes specifications and materials properties. This module uses ANNs (Artificial Neural Networks) methods for creating tools/processes/materials models, which can be trained using data from forming trials and theoretical models of aluminium alloys' sheet forming processes concerning e.g. minimum die radii, clearance between die and punch, heat treatment temperatures, material thickness, etc. These ANNs models can express any relation of tools details and processes parameters values with high accuracy, since the proposed ANNs approach can express almost any kind of Tools/Processes/Materials relation (e.g. multi-variable function models, linear or non-liner models with m inputs and n outputs where m≥1 and n≥1). Using the ANNs methodology and the proposed ANNs models creation, it is possible, not only to predict and estimate tools design details in relation with process parameters and material specifications, but it is also possible to work vice-versa, which means to estimate process parameters values and needed material properties in relation with product and tools design details. The KBES Web module developed within this project can create and train Tools/Processes ANNs models with up to 10 input values and up to 10 output values. The system developed was tested for both single output and multi output ANNs models with satisfactory results concerning the modelling accuracy. For example in the case of a model with 3 Inputs (Raw Material Upper Tensile Strength in MPa, Material Thickness in mm, Minimum Radius of the Die Top Corner in mm) and 4 Outputs (SHT Temperature in ^{o}C, SHT time in min, Press speed in m/min, Clearance between the die and the punch in mm), the achieved modelling accuracy was less than 0.4% for all the 4 estimated model outputs. More information and description about the functionalities of the KBES Windows and Web modules is given in deliverable D4.3 (A Knowledge Based Engineering System – KBES for HFQ aluminium).

<u>Validation of the FE modelling results in relation with HFQ experimental trials</u>

After the CDM (Continuous Damage Mechanics) model was fully integrated into the PAM-STAMP package, the complete HFQ Finite Element (FE) modelling solution was ready to be validated in relation with experimental trials of the project. The complete FE-HFQ-Modelling-System can address all various aspects of the physics involved in the process including: Thermo-mechanical material model for the blank, Temperature dependent deformation behaviour, Strain Rate dependent deformation behaviour, Heat transfer (conduction, convection and radiation), Tooling/blank interaction, Temperature, pressure, gap dependent heat transfer between blank and tooling, Heat transfer between tooling and coolant, Quenching: pure thermal as well as thermo-mechanical for the die in advanced model. Also it can investigate and resolve problems associated with the process itself and formed parts including: Percentage Thinning (Cracks), Blank shape, trim-line and wrinkle, Temperature and Microstructure (Cycle time, Hardness, Distortion). Engineers in Automotive and Aerospace, can now use the new system to carry out typical: (a) Feasibility modelling: To check the feasibility of the hot forming process (wrinkles, rupture, hardness) with minimum simulation time, using a constant tool temperature, and (b) Formability modelling: To check the formability of the hot forming process (wrinkles, rupture, hardness) with highest precision, using a variable tool temperature depending on process conditions. The modelling results of 3 of the project demonstrators were validated in relation with the HFQ production results of these 3 parts. The 3 demonstrator parts were:

(1)The door inner

(2)The B-Pillar part.



(3)The aircraft seat arm-rest.

Analytical HFQ FE-modelling was implemented for the above parts and the modelling results for e.g formed parts' thickness distribution, plastic strain contours, distances between formed sheet and die surfaces, etc. were compared with production results and after the 3D scanning of the HFQ formed parts using CMM (Coordinate Measuring Machine) scanner.

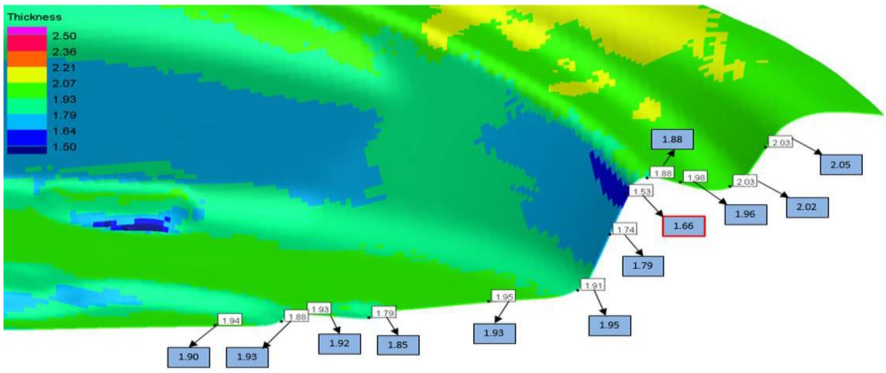


Fig 3.4.6 Example of HFQ-FE thickness modelling comparing prediction with real measurements

Analytical description of all the HFQ-FE-Modelling system capabilities & functionalities and the modelling validation results for the above 3 cases of the experimental forming trials can be found in deliverable D4.4 (Validation Report on the FE modelling system and case studies).

3.5 Work Package 5: Process and Manufacturing system integration

The work-plan of WP 5 was subdivided into 3 key tasks as outlined below.

- Establish a model for the HFQ production system
- Design an integrated production system for low cost HFQ aluminium
- Develop a cost model for HFQ aluminium

Establish a model for the HFQ production system

The process design specifications employed for the model integrated production system development in the HFQ hot stamping process are illustrated in Figure 3.5.1.

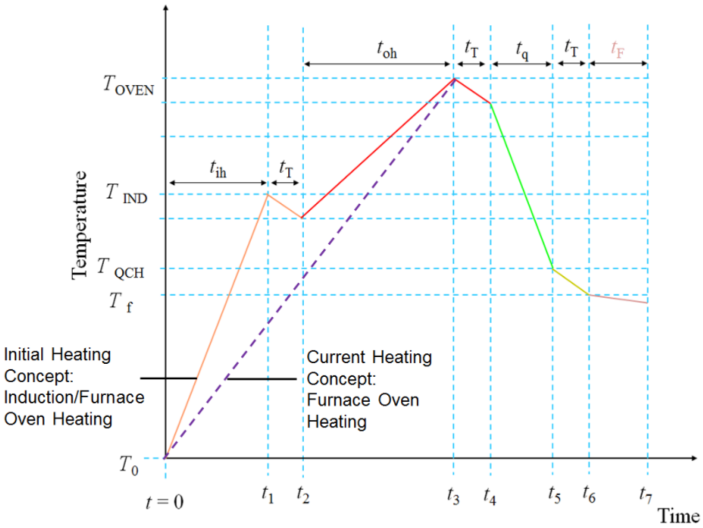


Figure 3.5.1. Process Definition for HFQ Hot Stamping Process

The parameters illustrated in this Figure are defined as follows: T_{IND}: Induction temperature, T_{OVEN}: Oven temperature, T_{QCH}: Quenching temperature, T_f: Forming temperature, t_{ih}: Induction heating time, T_{oh}: Oven heating time, t_q: Quenching time, t_F: Forming time, t_T: transfer time. The defined transfer time t_T is significant in the design of transfer systems for the HFQ hot stamping process. This transfer time is associated with the HFQ hot stamping process through temperature gradient, which is given as:

$$\frac{dT}{dt_T} \leq 10\ °C/s$$

where dT represents change in aluminium alloy blank temperature during transfer. The specified temperature gradient ensures achievement of the specified mechanical properties of the manufactured component. The production-line layout structure depicted in Figure 3.5.2 was mainly based on the process definition illustrated in Figure 3.5.1 above as well as the background knowledge of AP&T in hot stamping process. The design considerations in the layout plan enable flexibility for the HFQ hot stamping process.

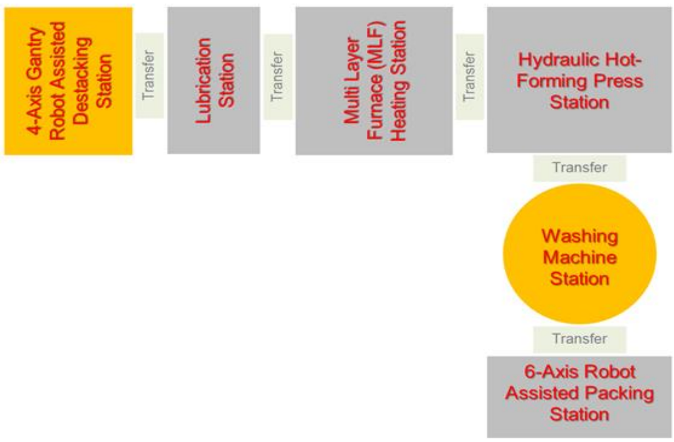


Figure 3.5.2. Production-Line Layout Structure

As illustrated in this figure the layout structure concept starts at the 4-axis gantry robot assisted destacker station to feed the Al-alloy blank sheet to the process route. From the destacker station, the blank sheet will be transferred to the lubrication station before the Heating station. At the Heating station with the AP&T multi-layer furnace (MLF), the blank sheet will be soak-heated (solution heat treatment) at the specified temperature and time for the used Al-alloy blank sheet. The transfers to the MLF are through the AP&T Furnace Feeder. According to Figure 3.5.2, in the next step the blank will be transferred to the Hydraulic hot-forming press station to shape the hot blank sheet. To enable precise hot blank sheet placement for the forming process, the transfer and handling system to feed the press station involve the speedfeeder systems. After the forming process, the shaped component will be transferred to the washing station to remove the applied lubrication before the heating process. As shown in Figure 3.5.2, the 6-axis robot assisted packing station represents the last station in the developed production system. The efficiency achievable with the Layout plan illustrated in this Figure will enable the integration of other processing stations such as Artificial Aging and Intermediate cooling stations as maybe required in the HFQ hot stamping process. Additionally, the layout concept design can easily be reconfigured to process other materials as well as different process definition.

Design an integrated production system for low cost HFQ aluminium

The developed complete "Turnkey" production-line model by AP&T according to the layout structures is depicted in Figure 3.5.3. This developed model represent the 3D models presented at the 18th Month Review Meeting in Greece and at International Conference of New Forming Technologies (ICNFT2015) in Glasgow by AP&T. This complete "Turnkey" production lines developed for the Al-alloy HFQ hot stamping process, are designed to enable automatic handling from sheet metal to the formed components and based mainly on the proven modular concepts by AP&T.

Figure 3.5.3. AP&T Developed Model Production-Lines for HFQ Hot Stamping Process

The production-line models shown in this Figure provide high flexibility to produce wide range of automotive structural components from Al-alloy materials. The developed models enable high speed processing requirements in the HFQ hot stamping process. The press is equipped with a high speed hydraulic system and the linear automation system that allows precise, repeatable and damage-free part handling at the specified transfer speed.

The production line destacking station is equipped with one 4-axis Gantry robot for destacking, double blank control with integrated identification marking device (ID-marking) for blanks sheets. The ID-marking enables to trace errors in the process chain of the HFQ hot stamping process. The lubrication station enables adequate application of lubricant on the Al-alloy blank sheet.

The hydraulic hot-forming press is characterised by press force of 6000 kN and bed size: 3000 mm (wide) x 2200 mm (deep) to provide the required forming force. The Press system is also equipped with high-speed multi-circuit system. Further, integrated SpeedFeeder system for the lubrication station and 2-SpeedFeeder system for furnace (oven) heating station ensure effective and efficient handling and transfer systems for the lubrication and the heating stations. Also included in the handling and transfer systems are: 1-SpeedFeeder system for Press loading and 1-SpeedFeeder system to unload the press as well as exit conveyor for the shaped components from the press station. All grippers and fixtures in the handling and transfer systems have a quick lock system for fast replacement and satisfy the general standard of the European Conformity regulations (CE-Marking) or EU regulatory requirements for safety. AP&T safety systems and guarding were all designed in line with the requirements of the CE-Marking. The integration of the production-line components is achieved through the line control system developed for production-line control system.

The significance of cost in manufacturing makes cost assessment of a production-line as presented in Figure 3.5.3 above needful. According PAB, the investment cost of this production-line is valued at £6m. Based on the current rates of interest of borrowing this money is £1.5m, giving a total investment cost of £7.5m. On the additional operations cost: an estimated rate of £600 cost per hour will be associated with this production-line. This is based on £500 cost per hour on a conventional AP&T production-line added to an estimated differential-cost of £100 between the conventional production-line and the HFQ process production-line costs. The differential-cost represents the additional challenges in HFQ process compared with the conventional hot stamping of boron steel.

To establish the annual operating costs, based on investment cost of £600 per hour: 24-working hours per day was multiplied by 5-working days per week to give 120-working hours per week. Considering 47-working weeks in a year in most countries such as UK, 5640-working hours per year can be estimated. On this bases a total of £5,640 cost per annum can be established for an interruption-free HFQ process operation-cost. Considering 5-years amortisation period: “Pay-back” on the investment after the 5-years period would amount to £28,200 (£5,640 x 5). To give the total hourly costs of buying the production-line: the initial investment cost of £7.5m, will be divided by £28,200 to give £266 per hour buying-cost of the production-line. An estimated running cost of £100 per hour for productions include: power, water, air and other consumables, with material costs valued at £2.50 per/kg. In addition, £90 per hour labour costs will be expected as well as £40.50 per hour working at 45 % the overheads. This gives a total operational hourly cost of £496.50 for the production-line and to represent cost only.

Further on material costs, most major aluminium suppliers use a combination of recycled and pure aluminium to produce either continuous cast sheet or plate, or to produce slab, billet or ingot at minimum cost. The proportions of recycled to pure aluminium depend on the final requirements for the alloy and the availability of the right quality of scrap aluminium. Production of pure (primary) and recycled (secondary) aluminium are energy intensive process whose costs are closely related to the source of the energy; hydro-electric, nuclear, etc. However, it should be noted that re-melting or re-cycling of aluminium uses only about 5 % of the energy needed to extract aluminium atoms from ore. Scrap mining is carried out on a very large scale in order to take advantage of the reduced energy requirements needed to produce one tonne of metal and in order to satisfy the increasing demand for aluminium products at minimum investment cost. The Aluminium Association produced a sustainability report in 2011 which clearly shows this trend in North America.

Some alloys are difficult to cast, while others show significant challenges in a rolling process. These alloys require specialist facilities, greater machine time and more primary quality scrap from side and end trimming operations. Solution heat treatment of certain high strength alloys is significantly slower than for others and contributes to cost of production, since continuous heat treatment line speed is directly related to the cost. The cost of sheet aluminium production is propriety information that is different for each rolling mill. Aluminium price lists give an indication of the major contributing factors to the effective material costs. Some of these processes however may not be needed for materials required in the HFQ hot stamping process. Blank sheet of common alloys: temper or hardness may be purchased in small quantities from specialist metal stockholders, but their price is not indicative of prices that may be obtained directly from the coil or sheet producers. However, it is very difficult for coil manufacturers to provide small quantities or samples of material unless it is a large volume product that is already being cut to length for a customer. While small quantities can be cut from the supply for other customers, which adds to the process cost (de-coiling, roller levelling, cut to length and handling), it also runs the risk of producing an underweight coil that may disrupt the end users production process. It is important to estimate material requirements and discuss them with potential suppliers well ahead of production (usually three months) in order to avoid high premiums on the price or difficulties in obtaining the specified material.

Once the cost model has been tailored for the internal costing methods, the basic process can be used to define the raw piece-cost of HFQ® components. However, a model to conduct piece-to-piece comparisons, based on production cost data alone, to traditional forming routes is not advised. For optimal cost model, the purchaser or buyer may need to work with engineers to understand the full cost savings from aluminium alloy grade materials to HFQ® production.

Develop a cost model for HFQ aluminium

Internal costing procedure is not consistent between companies. Costings are often confidential and can vary considerably in their build-up. For example, production volumes, location of customer production facilities and quality requirements are some of the key factors taken into account by material suppliers when assessing the desirability of direct supply and when quoting prices for their products. Vehicle manufacturers themselves have very well developed cost models and a vast bank of data concerning energy, raw material, component and overhead costs for their production facilities around the globe. In order to provide a useful base of information to update company cost models, the focus was on what to include in a cost build-up as opposed to an actual cost build-up. The cost model can be divided into 6 key stages: Vehicle product profiling, material definition, component design, design for manufacture, prototyping and production. Specific information for the cost model can be found in Deliverable 5.4.

3.6 Work Package 6: Industrial Validation, Implementation & Demonstration

The work-plan of WP 6 was subdivided into 5 key tasks as outlined below.

- Define and identify industrial requirements and demonstrator parts for automotive and aerospace applications
- Form the selected demonstrator parts using HFQ® technology
- Characterise mechanical properties of HFQ® formed parts
- Refine the manufacturing cost model for HFQ® aluminium
- Demonstrate the use of the integrated production system developed in WP5.

Define and identify industrial requirements and demonstrator parts for automotive and aerospace applications

The criteria for part selection as defined in D6.1 was that the part would need to showcase the benefits of the HFQ® technology (complex shape, lighter, stronger) whilst being economically feasible to manufacture and have good potential with market volumes. The light-weighting would be achieved through higher material grades, and complex geometries would allow for part consolidation.

The first parts studied were an aerospace Electronic Housing Box, Wing Stiffener Panel and Wing Rib. After sufficient research these parts were discarded as not being suitable for HFQ® technology, mainly due to either low production volumes, issues with the design, or that the benefits of HFQ® would not be utilised within the component. Although the Stiffener Panel would experience some of the benefits of HFQ® such as reduction in cost and weight, it was thought to be impossible to form solid ribs from a single sheet of aluminium and so it was not considered. The Wing Rib had a thickness of 30mm and so this could not be manufactured through a sheet stamping process without major re-design, and the introduction of potentially weakening rivets to bond together several sheets of HFQ® material. The aerospace part that was chosen was an interior aircraft Armrest Component. This had good potential for production volumes, showcased the HFQ® technology as there was a relatively deep draw, and was possible to be made from single sheet aluminium. For the automotive selection, the first part studied was the longitudinal cross member from CRF. The tooling was already in place for this, and there was a large potential volume. Other benefits to the project were that the partners would gain validation data and manufacturing experience. This part was the first to be manufactured and proved to be a suitable initial trials test case.

The Lotus Door Inner was the second panel to be chosen. This showcased the benefits of HFQ® technology in many ways; reduction of material cost, elimination of assembly steps, part consolidation, weight saving, large production volumes and a complex shape with a high draw (200mm) which could be manufactured in one step. Once again the tooling was available within the consortium.

The CRF B pillar was selected as the tooling was already available, and it was a complex geometry to form using HFQ® technology. There were weight and cost savings to be gained, and a large potential production volume. Although the tool was designed for steel manufacture, it was felt that the experience of the partners would off-set this problem and that a good part could be formed, and this was borne out during the forming trials in D6.3.

Form the selected demonstrator parts using HFQ® technology

With all of the forming trials the objective was to not just form parts but to get to a stage of repeatability in manufacturing good parts, and identifying a clear manufacturing process. The trials ensured that there was much learning gained about press parameters, heating control, blank development, blank handling, and use of lubricant. The trials also identified the best lubricant to use.

PAMSTAMP software was used for the forming simulations and partners were able to optimise predictive models by measuring the post-formed geometries and comparing them to the simulation work. The CRF Rear Floor longitudinal cross member was the first part to be formed. This was the first time that an HFQ® component had been formed in an industrial setting, and the first time that a part had been formed in AA7075 alloy. AA6082 was also used and this enabled post-forming research into the mechanical performance of both alloys, along with the formability of both and the differences between them. The Door Inner was a different challenge due to the complexity of the part and the sheer size of the blank. The depth of the draw and the tightness of the radii were also a challenge, and all simulation work predicted difficulty in forming with particular areas prone to splits, wrinkling and creasing. The handling issues were initially overcome with the use of tabs, although this had the negative effect of reducing material flow and increasing the difficulty of forming a “good” panel. After a series of trials, enough experience was gained with the handling, and with the introduction of location pins and other modifications on the tool, the handling tabs were removed and a fully developed blank which optimised formability was produced. It was also agreed that the most complex HFQ® part possible had been manufactured.

The CRF B Pillar panel was manufactured during two forming trials at AP&T, and used both AA6082 and AA7075 alloys. Simulation work had predicted splits in localised areas, and the tool had been designed for use with Boron Steel. More learning was obtained, particularly with the 7075 material, and it was found that increasing the transfer time from 10s to 20s and eventually 30s had a positive effect on forming. The understanding of the heating parameters also improved as the heat was reduced to 500 deg C in the oven, which meant the blanks were at 480 deg C.

Figure 3.6.1. CRF Longitudinal Cross Member and Lotus Door Inner

The trials also allowed for development of the use of lubrication. The tool was fully lubricated for one pressing and then a further two pressings were made without adding further lubrication. Localised lubrication was also trialled, added to those places that simulation had predicted would be a problem, and which forming trials had confirmed were a problem. All of this helped in increasing our understanding of the lubricant and how it worked with the materials. Any reduction in lubricant would help with productionising the HFQ® process in a high volume environment.

Figure 3.6.2. CRF B-pillar and Aircraft Armrest Components

Simulation work on the aircraft armrest component had optimised the blank shape, but for AA6082 material only, and had also predicted several areas for splitting. The forming trials also used AA7075 material however the results of using AA7075 were consistent with the simulations. Further understanding of the heating parameters of the forming temperature was gained – it was found that increasing the transfer time to 30s gave better forming results, and the oven temperature was reduced to 490 deg C which meant the blanks temperature was 470 deg C.

The plasma nitrocarburising by Bodycote plc followed by the coating of tools by AIN is something that would require further research and investigation as it was only available for the last day of trials with the armrest. Particularly, the benefit of plasma treatment to the durability of tool needs further investigation. It was found that the nitrocarburised cast iron tool successfully formed armrest with lubrication. It was learned that lubrication was still required to produce good parts, however, a further 4 pressings were made without adding further lubrication — which doubles the number of parts it can form without adding lubrication using untreated tools.

The steep draw and the extremely tight radii of the part had caused problems with the machining of the tool, and as such it was felt that with more development it would have been possible to redesign the tool and produce a better part. It was felt that with the tool as it was then the best possible part had been manufactured. It was felt that all of the trials held had been a success, much was learned, and parts had been manufactured that resulted in savings being made in weight and manufacture process time. The hardness testing that had been conducted on the aged parts was very encouraging, although for the Armrest trials the fact that the AA7075 material was clad in pure aluminium has presented some questions that require further research. Research has been done into fast ageing which will reduce the manufacture time and make the HFQ® even more attractive to potential customers.

<u>Characterise mechanical properties of HFQ® formed parts</u>

A detailed investigation was conducted into the mechanical property distribution of the HFQ® formed parts with the objective being to develop an in-depth understanding of the material science and the materials processing technologies. This has the ultimate aim of the process meeting specified mechanical/microstructural properties for automotive and aerospace applications, and so that fast Solution Heat Treatment and ageing can be achieved, something that is vital for high volume manufacture in an industrial environment.

D6.5 has delivered an understanding of the mechanical properties and microstructure of the formed parts after forming and ageing, and examining the size and type of precipitates. Based on these results, the ageing process was refined according to the effect on the microstructure of the sample areas. The oxide layer was also examined, with the chemical composition and the surface morphology being quantified by use of EDX and SEM.

The hardness studies on the AA6082 CRF B pillar was carried out before and after artificial ageing. Before artificial ageing a 2 month period had elapsed and so the effect of the natural ageing that had occurred meant that there was a relatively high hardness of the sample sections. Artificial ageing was carried out with variable ageing times ranging from 1 to 8 hours. Although it suggested the optimal ageing time was relevant to the strain, the artificial aging did not increase the maximum hardness significantly. Therefore, the effect from the natural aging and the previous SHT condition need further investigation.

The pre-deformation introduced by Gleeble tensile testing after solution heat treatment has a significant impact on the response of the deformed AA6082 material to subsequent aging at 180°C in terms of the maximum hardness (i.e. peak hardness) after aging and the optimal aging time to achieve the peak hardness. The optimum aging time for the sample without pre-deformation is 8 hours, which is the same as for T6 condition, whereas the optimal aging time corresponding to the 25% and 30% strain dropped to 3 hours. It also showed the reduced peak hardness (100-106HV0.3) on strained parts. In terms of surface morphology and chemical composition, it was found that MgO was present on all coated (PT2) and non-coated parts after Solution Heat Treatment. The AA6082 was not significantly changed by the effects of SHT temperature (510 deg C) of AA6082 on its chemical composition. However, the SHT used for AA7075 (476 deg C) was high enough to allow migration of Mg and Zn to the surface, and the SHT of AA5754 (535 deg C) was high enough for certain elements to migrate to the surface and change the PT2 coated 5754 coating composition visibly and chemically.

Refine the manufacturing cost model for HFQ® aluminium

The cost model was very difficult to generate due to commercially sensitive information that could potentially expose SME's pricing policy to a wider audience. In consultation with PAB and ITL, MAR found that it would be most beneficial to produce a model that identifies the major differences between HFQ and hot pressed Boron steel. A matrix was produced defining these differences and can be used as the basis for more detailed studies. A total of 51 lines of data were required to be input so that meaningful costs could be obtained. All costs were considered at every step of the process; material, lubrication and associated costs, furnace costs (SHT and ageing), press and trimming operations, cleaning, transport and shipping costs. The result is that a working, adaptable cost model has been produced which gives an in-depth comparison between HFQ® manufactured parts and the existing technology.

Demonstrate the use of the integrated production system developed in WP5.

From all of the forming trials the following criteria were considered for designing the HFQ® production cell (i) Blank handling, transfer speeds, heating rate, cooling rate during transfer, temperature drop during quench, (ii) Industrial application of HFQ® processing technology to

Aluminium alloy panels, (iii) Formability of AA6082 and AA7075, (iv) Forming speed, temperature, forming force and blank holder force, (v) Dry forming and lubrication, application and cleaning of lubricant, (vi) Tool performance – arrangement, wear and temperature control, (vii) Blank location on tools, (viii) Data acquisition methods.

The trials gave a good basis for refining these criteria and for establishing the best process methods of HFQ® manufacturing in a production environment. This deliverable was based on the AP&T line in Sweden and although this was designed for hot stamping of boron steel, it did enable learning to happen within the consortium. All of this learning was put into practice with the installation of a unique, dedicated HFQ® manufacturing line at CIPCO in Coventry which is now producing HFQ® components for the automotive industry. This CIPCO line is tailor made for aluminium with a speed of 350 mm/s, bed cushions to enable 3 part tooling and ovens specific for use with aluminium. D6.4 recommended measures to optimise the production cell to achieve high manufacturing efficiency. These measures included fast heating and cooling, fast ageing, robotic cleaning unit, and design and manufacturing considerations on the assembly and joining of formed parts.

3.7 Work Package 7: Dissemination, Exploitation, Training and Educational Courses

The work-plan of WP 7 was subdivided into 5 key tasks as outlined below.

- Further development of commercialization route and business plan for HFQ aluminium
- SME specific activities
- Project Training Programs
- Exploitation and Dissemination
- Innovation Related Activities and IPR Management

Further development of commercialization route and business plan for HFQ aluminium

At the end of the LoCoLite project, Impression Technologies Ltd (ITL) has a fully operational commercial HFQ® production line that produces parts for the niche volume sector. ITL works as a supplier to consortium member PAB to offer a commercial production route for HFQ® formed panels.

Going forward, ITL aims to license the HFQ® forming technology globally. In a similar method to that described in Deliverable 7.3, a HFQ® club (described as a virtual enterprise in D7.3) is under development as a means to roll out the technology quickly and widely. The intention is to make HFQ® the manufacturing method of choice for complex, high-strength aluminium pressings.

Further, it is ITLs intention that HFQ® becomes a global standard. To achieve this, ITL will continue to work with partners to nurture and develop the supporting environment to enable high-quality design, simulation, tooling and production to a set of standards that guarantee quality.

SME specific activities

The aim of this task is to keep under control the technical and business developments in order to boost the SMEs participation and benefit from the emerging technologies and products. Therefore, in particular AIN has worked on the subject investigating the state-of-the-art of the technology and stakeholders in aluminium forming, in the automotive as well as in the aerospace sectors. The work was divided in the analysis of various large-volume markets for which the Al forming and HFQ in particular has potential impact. Such markets include automotive (cars and trucks), aeronautic and other applications (construction, home appliances, etc). The market search has included a patent analysis on Al-forming technologies (>150 patents identified), and the analysis of the owners and therefore on who is who in the Al-forming production chain. The major drivers for the realization of the HFQ impacts are concentrated on the transport sector, and are, (i) the growth forecast for transport vehicles, including cars (fueled, electric or hybrid), trucks and aircraft, (ii) the public regulations targeting restrictions of pollutants production in transport. This leads vehicle manufacturers to find strategies of weight reduction as the most effective way of energy saving and (iii) the need for using more recyclable materials. Aluminium fulfils this demand.

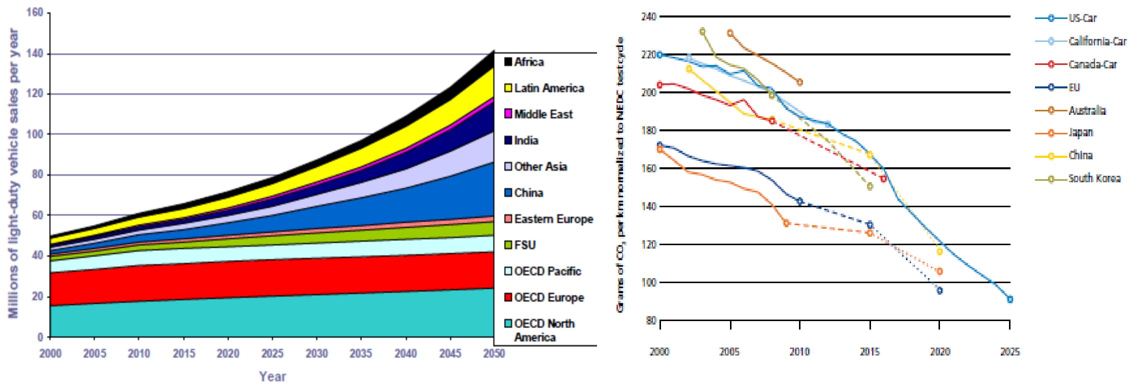


Figure 3.7.1. Example of global forecast evolution of the car-truck market (left) and objectives of CO2 emissions reduction (right) [2]

The main industrial sector results to be transport with a share of more than 1/3 of the total market. The trends in these sectors are expected to be steadily increasing, which encourages the involvement of the smaller companies, for which the opportunities related to the technologies involved in the implementation of HFQ have been identified: the tooling-making sector, surface engineering, FE-modelling, recyclability are novel market opportunities which can be beneficial for SMEs. Some of these figures are well represented in the consortium, and for some of the above-listed roles, they represent 50% of the market share, up to 70% in the case of maintenance roles. Finally, a search work for the identification of EU-wide relevant people involved in the automotive, aeronautic, construction, appliances, coating engineering, materials, etc. has been done. A list of nearly 250 people of companies like AirBus, VW, Renault, Boeing, and several others has been attained. The search has been done using scientific databases, and it has been used for dissemination of Newsletter, following the regulations of data protection.

Project Training Programs

After the successful training sessions of the first period, in the last 18 M a special training session has been dedicated at the M 24 meeting to the PFMEA for the HFQ process, which has been led by G. Adam of ITL. All the partners have been actively involved in a brainstorming session for the analysis of the production process, as shown hereafter. At the M30 meeting, all the partners could finally see how HFQ works in reality, attending forming trials and learning the details of the stamping press.

Exploitation and Dissemination

In the second half of the project, dissemination activities have been continued by all the partners, with participation to exhibitions, conferences, as well as with publications, at scientific and at industrial level. The newsletters n. 4 and 5 (special final issue) have been released and circulated among the partners and sent to more than 400 external contacts throughout the world and transversal to many industrial sectors.

Figure 3.7.2. Issues 4 and 5 of the Locolite newsletter

A list of events where LoCoLite partners have participated in the last 18 months is reported hereafter.

n.	Date	Type of activity	Ben.	Title	URL
28	6/08/2015	Articles published in the popular press	UoB	ICNTFT 2016	DOI: 10.1051/matecconf/20152105009
29	2016	Organisation of Workshops	TBZ	BOMBARDIER	http://de.bombardier.com/content/germany/de/about-us/bombardier-in-country/sites/site.transportation-hennigsdorf.html
30	30/8/2015	Articles published in the popular press	TBZ	MACHINENMARKT – MM36	http://www.maschinenmarkt.vogel.de/index.cfm?pid=2054
31	16/11/2015	Videos	DIG	Video of the ICNFT2015 in Glasgow	LOCOLITE YOUTUBE CHANNEL
32		Web sites/Applications	DIG	TWITTER ACCOUNT	LOCOLITE TWITTER ACCOUNT CREATED @locoliteeu
33	14/1/2016	Articles published in the popular press	APT	AP&T leverer verdens første produktionslinje til varmformning af aluminium efter HFQ-metoden	http://www.altomteknik.dk/nyheder/2016/01/14/apt-leverer-verdens-foerste-produktionslinje-til-varmformning-af-aluminium-efter-hfq-metoden.aspx
35	11/4/2016	Exhibitions	APT	Mach 2016	http://www.machexhibition.com/
36	26-28 April 2016	Exhibitions	ITL	5th GALM Europe - Global Automotive Light Materials 2016	http://www.global-automotive-lightweight-materials-europe.com/
37	24/2/2016	Articles published in the popular press	APT	Blechnet AP&T liefert erste Produktionsanlage mit HFQVerfahren	http://www.blechnet.com/index.cfm?pid=2907&pk=522481&cmp=nl-94
38	1/2/2016	Articles published in the popular press	APT	Maskinoperatoren n.1	
39	9/2/2016	Articles published in the popular press	APT	Första produktionslinjen för varmformning av aluminium	http://www.motormagasinet.se/alla/forsta-produktionslinjen-for-varmformning-av-aluminium/
40	17/2/2016	Articles published in the popular press	APT	Varmformning av aluminiumdelar	
41	10/2/2016	Articles published in the popular press	APT	Världens första produktionslinje för varmformning av HFQ®	http://qimtek.se/news/varldens_forsta_produktionslinje_for_varmformning_av_aluminium_enligt_hfq%C2%AE-9387.html
42	1/3/2016	Articles published in the popular press	APT	HFQ aluminium forming line	http://www.ismr.co.uk/news/hfq-aluminium-forming-line.html
43	25/2/2016	Articles published in the popular press	APT	AP&T first to produce line for hot forming of	http://www.thefabricator.com/news/stamping/ap-t-first-to-

				aluminum with HFQ	produce-line-for-hot-forming-of-aluminum-with-hfq
44	1/2/2016	Articles published in the popular press	APT	varldens-forsta-produktionslinje-for-varmformning-av-aluminium	http://www.aktuellproduktion.se/2016/02/varldens-forsta-produktionslinje-for-varmformning-av-aluminium/
45	3/2/2016	Flyers	DIG	Newsletter n.4	
46	1/2/2016	Articles published in the popular press	APT		http://www.verko.se/pdfer/bransch216/varmfomning.pdf
47	1/2/2016	Articles published in the popular press	APT	AP&T PRODUCES A PRODUCTION LINE FOR HOT FORMING OF ALUMINUM WITH HFQ	http://www.ffjournal.net/item/13572-apt-produces-a-production-line-for-hot-forming-of-aluminum-with-hfq.html
48	16/2/2016	Articles published in the popular press	APT	AP&T Produces A Production Line For Hot Forming Of Aluminum With HFQ	http://www.modernmetals.com/item/13190-apt-produces-a-production-line-for-hot-forming-of-aluminum-with-hfq.html
49	24/2/2016	Articles published in the popular press	APT	AP&T liefert erste Produktionsanlage mit HFQ-Verfahren	http://www.maschinenmarkt.vogel.de/apt-liefert-erste-produktionsanlage-mit-hfq-verfahren-a-522480/
50	10/2/2016	Articles published in the popular press	APT	Produktion i bara ett steg	http://www.verkstaderna.se/kategorier/verktyg-maskiner/produktion-i-bara-ett-steg/
51	10/2/2016	Articles published in the popular press	APT	Premiärleverans för AP&T	http://www.metal-supply.se/article/view/239679/premiarleverans_for_apt?ref=newsletter#.VrsK202FNmM
52	9/2/2016	Articles published in the popular press	APT	Produktionslinje för varmformning	https://www.industritorget.se/nyheter/produktionslinje+f%C3%B6r+varmformning+/11077/
53	11/4/2016	Articles published in the popular press	APT	Verk Staderna n. 3-4; AP&T levererar unik linje till Cipco	
54	june 2016	Articles published in the popular press	APT	AP&T FIRST IN THE WORLD TO PRODUCE A PRODUCTION LINE FOR HOT FORMING OF ALUMINIUM WITH HFQ®	www.britishmetalforming.com
55	7-8 sept 2016	Oral presentation to a wider public	ESI	EUROSPF 2016 CONFERENCE TOULOUSE, FRANCE	https://eurospf2016.sciencesconf.org/
56	18/10/2016	Oral presentation to a wider public	ITL	EuroCarBody 2016	www.automotive-circle.com
57	oct-nov 2016	Articles published in the popular press	ESI	Benchmark Magazine	https://www.nafems.org/publications/benchmark/
58	1/11/2016	Flyers	DIG	Newsletter n. 5	

Innovation Related Activities and IPR Management

The project website has been managed by ANTER, with continuous updates for both partners and external contacts. Data from the Google Analytics application show that in last year the website has been seen from many parts the world, even far from EU.

	377 % del totale: 100,00% (377)
1. United Kingdom	56,23%
2. (not set)	12,47%
3. United States	7,16%
4. Iraq	4,77%
5. Russia	4,24%
6. Austria	2,92%
7. Switzerland	2,39%
8. Saudi Arabia	1,86%
9. Japan	1,06%
10. South Korea	0,80%

Figure 3.7.3. Distribution of the accesses to the Locolite webpage

During the LoCoLite project ITL and many of the other partners have discussed HFQ® with OEMs and tiers, including partner OEM CRF and partner tier PAB. The wider market for automotive lightweighing technologies has increased significantly during the three-year project period and there is every indication that this trend is set to increase as engine technology reaches a plateau and battery technology, that requires a light-weight body structure for range, becomes more prominent. HFQ® is starting to appear as a key enabler within the automotive aluminium ecosystem.

The Intellectual Property generated by partners can be defined as 'know-how' and 'patentable'. Imperial College have patented further technologies relating to HFQ® and all parties now have specific know-how relating to the design, production and analysis of HFQ® panels, tools and equipment.

Examples include but are not limited to: Fast Material Ageing (ICL); Lifecycle Analysis (DIG, MAR); Quality (ITL, PAB); Production equipment (APT, ITL, STR); Die materials (UOB, AIN, PLA and others). ITL and PAB have an agreement in place to produce HFQ® panels commercially and cars featuring HFQ® panels have now been launched. ITL and APT have jointly presented the HFQ® technology at shows (such as MACH 2016).

ITL is working with other Tier 1s and OEMs globally to roll out the technology. Many of these links are in the early stages and will not be made public for several months or possibly years. Many of the consortium members will continue to work together for the EU funded LoCoMaTech project, which aims to improve upon the base technology to improve its suitability for high-volume manufacture.

4. Potential Impact, main dissemination activities and exploitation of results

The automotive industry supports more than 12 million jobs [3], and the aeronautic sector employs some 700,000 people and encompasses over 2,000 companies and 80,000 suppliers in EU countries. In terms of market demand, at present, there are 60 million passenger cars produced in the world pa and one third of them are produced and used in Europe with a value of over €500bn [4]. Moreover, 35% of the cost for a passenger car is related to body and chassis structures, which relates to the creation of a wealth of over €180bn pa for Europe. Currently, over 95% of car body and chassis structures are made of steel [5]. Replacing these structures with aluminium alloys would lead to up to 40% weight reduction on average, with a fuel saving of up to 23% and hence, a significant reduction of CO2. Assuming the average mileage of a passenger car to be 15,000km for a year, the fuel saving would be more than 48 billion litres pa, considering that over 720 million new passenger cars with parts made with the HFQ techniques could be in service globally. If trucks, buses and mini-buses are considered, the amount of CO2 reduction could be doubled. Moreover, it is important to recognise that the automotive industry is facing a step change due to the requirements of Full Electric Vehicles (FEVs). The sale of "conventional" cars in 2011 decreased about 1.7% and micro and city cars, with weights lower than 1000kg, increased. This sector will be dominated by electric cars in 2018, as the new generation of €15k FEVs with 250km range will be available [6]. Lightweight structures are of key importance to FEVs, as light weight will be fundamental to delivering optimum performance. The performance of FEVs will be central to OEMs being able to gain market leadership.

Research to promote applications of lightweight structures in vehicles is a global effort largely due to fierce competition, especially in the automotive sector. EU framework programmes have funded some projects (e.g. FP5: ComposiTN; FP6: Super Light Cars; FP7: E-LIGHT) in the past, but LoCoLite is based on a solid industrial background with a patented materials processing technology and it significantly advances the materials processing technologies. To attain a large impact an EU-wide team encompassing SMEs with a widespread presence (eight SMEs within the consortium from eight EU countries) and communication capabilities with the automotive and the aerospace companies (CRF, HAI, DIG) as well as top class universities in the metal sector (ICL, STR & UOB) was established. The stamping industry (PAB), tooling (AIN, TBZ, PLA), equipment technology development and suppliers (APT), and, aluminium specialist (MAR) as European SMEs have been involved in the project.

The primary impact of developing the technology of the project was to apply a new, patented technology (HFQ) which has been proven in a small scale setting into a low-cost mass-production environment by manufacturing high strength complex-shaped lightweight panel components. This is expected to significantly increase the competitiveness of European automotive and aerospace industries.

The application of HFQ technology is estimated to result in large weight savings of approximately 40-55% depending on the grades of aluminium alloys selected which can result in Fuel savings of 20-25%, and CO_2 Emission reductions of 28.6-35%, depending on models. For full electric cars, the travel range can be increased by 30-35%. This can also have an enormous impact on the environment as according to life cycle analyses, over 90-95% of energy is used in-service for land vehicles. The energy use for materials processing and manufacturing only takes less than 10%. However, this technology could reduce the energy use in component manufacturing and assembling by 20-30% compared with the current manufacturing technologies for aluminium car body structures.

The technological results of the project have demonstrated a totally new industry system-technology (including innovative processing routes, advanced material-heating and handling designs, innovative tooling and press-technology) to produce high strength, complex-shaped aluminium parts with considerably low costs. This novel technology has the potential to reduce the price of aluminium components to be adopted on medium and high volume vehicles. The HFQ process has been proven to produce automotive and aerospace components from standard grades of aluminium sheets (5xxx, 6xxx, and 7xxx series), which have been formed into shapes as complex as those produced from sheet steel. Moreover, large complex shapes were produced in a single pressing which have enabled significant reduction in fabrication costs by eliminating joining of multiple sheets, which has resulted in cost competitive components for chassis and body in-white assemblies.

Scientifically, there has been new understanding of the materials and modelling capabilities which have enabled the process to be optimised scientifically. Moreover, the project has established new systematic theory and scientific methods for applying the HFQ aluminium process to industrial situations, which has not been performed previously. Theories and materials testing methods have been established to enable the formability of the material at HFQ processing conditions to be predicted. This has greatly helped in the knowledge sharing with the participating SMEs which have limited R&D capacities.

Economically, the project has enabled lightweight body and chassis structures for passenger cars to be produced at lower cost than with existing technologies. This is demonstrated in Fig. 4.1 with an estimation of the selling price for a car door-inner made from the HFQ process. Compared to the forming of individual aluminium parts, followed by assembly, the manufacturing cost using the HFQ process and production system could be reduced by 50 %. A conservative estimation is that 50% of cars will be made with aluminium body and chassis structures due to introducing the HFQ process and the associated production system. A weight saving of over 40% for the Class D, C and above segment vehicles (which are currently made of steel) can be achieved when using aluminium parts, which would lead to fuel consumption savings on average, of up to 23%. This will result in a significant economic gain, considering over 60 million passenger cars being produced in the world pa. In aeronautical applications, material savings for selected panel parts could be up to 90% and manufacturing cost reduction over 95%, compared to that currently made by machining.

An example of the cost analysis per part (Door Inner)

								Cost on Year Base
Total investment on a machine (one-off)						€ 2,500,000		
Capital cost and Depreciation over	10	years					€ 250,000	
Production area for the production system		area (m2)				120		
Surface rent rate (year base)						€ 500	€ 60,000	
Maintenance costs	(%age of Investment)					5%	€ 125,000	
Total Fixed plant costs								**€ 435,000**
Material Data								
Sheet blank cross section length (n	1.5	width	1	thickness	0.0015	volume (m3)	0.00225	
Material density	2700 Kg/m3			Materials price €/Kg		2.5		
Raw Material cost per piece					21.26 €			
Other raw materials					0.55 €			
Scrap Recovery	(assume 50%)				-3.04	40%	Material loss	
Total Material cost per piece					18.78 €/piece			
Parts per hour (on an average)	300	Working hour per day			21	Working days/year	240	
Total parts per year					**1,512,000**			
Total Material Cost per year								**€ 28,387,800**
Direct Labour Cost								
Unskilled worker	production runs, maintenance	€ 30,000		Number	12	Total	€ 360,000	
Skiller worker	analyses, machine setup	€ 35,000		Number	3	Total	€ 105,000	
Manager/Foreman	(responsible for 10 lines)	€ 40,000		Number	0.1	Total	€ 4,000	
Total Direct Labour								**€ 469,000**
Electricy and/or gas per part					€ 1.77			
Total cost of electricity and gases								€ 2,676,240
Tooling costs								€ 450,000
Total Direct Costs								**€ 32,418,040**
Other indirect cost including overheads (including electricity, air, water, etc.)						60%	of direct cost	€ 19,450,824
Industrial gain						15%	of total cost	€ 7,780,330
						Total Manufacturing Cost		**€ 51,868,864**
				Part Cost			**€ 34.30**	
						Total cost of sales		**€ 59,649,194**
				Part selling price			**€ 39.45**	

Figure. 4.1. Selling Price per part for a Door Inner

The application of the HFQ technology and developed production systems will lead to significant economic and employment growth on a scale not achieved before by similar EU projects in the field of materials forming. Although industrial and EU research projects have been conducted in the past with a focus on lightweight cars, this project has been based on a solid, patented-technology with results applicable to all car and aircraft makers. Some key estimates indicating the impacts of the technology are shown in Table. 4.1.

Table 4.1. Estimation of the HFQ production lines, jobs and business growth to be created

Year of Achievement	No. of HFQ production lines	No. of Jobs (production)	Total No. of Jobs (design, services, marketing, etc)	Annual Income (€Million)*
Year 4	1st production line in operation	25	130	€32.2
Year 6	10 lines for Auto; 1 for Aero.	280	500	€322
Year 8	50 for Auto; 3 for other applications	1,340	1,786	€1,610
Year 15	450 for Auto; 10 for other applications	11,550	15,000	€14,490
After 20 years	>2000 for Auto; >50 for others	>51,500	>65,000	€64,400

(*) Estimated by industrialists for automotive applications. One production line could produce 1.4million panels/year and average manufacturing cost (including materials) for HFQ = €23/component.

Furthermore, regarding the aerospace industry, it is found that there are approximately 100 medium to large companies, mainly Tier 1 and 2 suppliers, followed by a vast number of specialized SMEs employing an estimated 200,000 employees across Europe with an annual turnover of €163bn. With the production of components through HFQ, there is significant waste material saving and cost reduction and also an enormous energy saving and CO_2 reduction.

In addition to the global and European impacts described, there has also been significant positive impact to individual consortium members of the project. As an example, the establishment of the first HFQ production line has been implemented by ITL to be used as a demonstrator development line as well as producing low volume complex-shaped components for weight reduction and cost saving of niche vehicles such as the Aston Martin (DB11) and Lotus Cars. Additional information can be seen on the following website: https://www.gov.uk/government/case-studies/new-aston-martin-db11-features-uk-firms-low-carbon-innovation.

Going forward, the application of HFQ components is targeted for Premier cars, such as Jaguar, Audi, Mercedes, and BMW. Work is currently underway to prove the feasibility for larger volume manufacturing which is expected to take approximately 2-3 years to enable the technology to be used on the vehicles. It is expected that costs will be reduced further during the period of further development of the technology. The long term aim for a period of 5-7 years is to further apply HFQ production to popular cars (Classes C & D), with opportunities in Trucks, Busses, Trains, and other aerospace applications for weight reduction and manufacturing cost saving. It is expected that some of the sectors will see application of HFQ within a 2 year period.

In addition, there has been an increasing order book for HFQ produced components. PAB has reported that there have been 8,000 panels manufactured using the HFQ method over the years 2015-2016. In 2017, there are 8,800 orders, 20,300 orders for 2018, 21,750 orders for 2019 and 20,200 orders for 2020. This has been made possible with the dedicated production systems developed as part of the project.

The first HFQ production line has been developed and implemented in CIPCO by APT to be used for demonstrator components. Further information can be found in the links:
http://www.ismr.co.uk/news/hfq-aluminium-forming-line.html and
http://viewer.zmags.com/publication/73bb9869#/73bb9869/38.

The large interest with pre-orders made from industry highlights significant potential for new business creation in Europe involving the sectors of modelling, tooling, materials and machinery to enable industrial implementation of the technology. These will be developed within EU, and hence, new business will be created, for example the Spin-off company (ITL) implementing the CIPCO press. New businesses will also be created in OEM design teams too, as a result of introducing design for HFQ to industry. The main business will be concerning the production - over 460 HFQ production lines are expected (worth over €14 bn) in the next 15 years.

The impact of individual components produced from HFQ can be summarized as:

Demo Part	**Market Penetration**	**Technological Benefits**	**Market for Extended Applications**	**Other Impacts (Social & Environmental)**
Door Inner for Vehicles (e.g. AA5754, AA5083 & AA6082).	50% of the market for passenger cars globally - suggests 120 Million parts pa.	Replace current Steel, resulting in >40% weight reduction; Replace current multi-part low strength Al assembly,	HFQ Al-technology can also be applied to the manufacture of bonnet inner, hatchback inner, plus, additional market for cars below Class C and	Reduce CO2 emissions in service and material-recycling; Reduce fuel consumption for each car by 23%; 85 production lines are predicted for this type

	The market size is about €7.3 Billion pa.	resulting in cost reduction by 50% of the parts.	D, which are about 350 Million parts pa, not even including parts for Trucks and Buses.	of components; 2125 new jobs on production lines can be created, and additionally, another 500 jobs can be created in other sectors.
Suspension arms (AA6111 & AA6082)	50% of the market for passenger cars – about 480 Million parts pa. Potential market size is about €2.0 Billion pa.	Ability to form thick panel materials with sharp radii for high stiffness (thickness: 2-3mm) while maintain good die quenching effectiveness.	Extended to chassis frames and assemblies. Due to the capability to form thick panels, the technology could be extended to other areas, e.g. construction, shipbuilding and railway engineering sectors.	It would require over 480 production lines overall, which would create directly new 8550 jobs for production, and 1200 associated jobs such as design and technical support jobs. Weight reduction: 60% compared to forged aluminium parts.
Floor panel (AA5754 & AA6082)	50% of the market for passenger cars – about 30 Million parts pa; Market size is about €2.6 billion per year pa.	3D large panel forming capability for different geometric features, high drawing ratios (up to 390mm in depth) offers new technological advantages.	Due to improved capability to form large 3D panels with complex features, the technology will find widespread applications in other sectors such as manufacturers of trains, large buses and ships.	It would require about 21 production lines which would create 525 new jobs for production and 200 associated jobs. Further weight reduction using high strength Al-alloys leads to positive impact to energy-saving and

				environment.
Wing Stiffeners for commercial aircraft (AA2024; AA7075)	On average, 14 wing stiffeners used in an airplane; Potential uses on all airplane wings.	Reduce production costs by 95%, material uses by 90% (replacing machining by forming).	Additional applications could be in Aircraft seats (currently using castings). Other machined panel parts could be made using HFQ.	20 production lines would be required, which could create 500 jobs directly; Further weight saving on components leads to lower fuel consumption for airplanes;

Finally, the direct economic gains of the project participants is summarised as follows:

Partners	Presence in Market	Direct Economic Gains	Impact on Turnover
ITL (SME)	Spin-off, the HFQ technology provider.	Royalty income from the use of the technology; Income from sale of additional process developments**;** More jobs for process development and process modelling services; More consultancy work for components design with OEMs and for Tier-1 on process and tool design.	> 500 % (Huge expansion)
PAB (SME)	Stamping specialist to automotive industry	Will be a production leader for production of HFQ Aluminium parts which will led to new customers and thus, additional sales. Expand their business from niche vehicle market to premier and popular cars. Opportunity to move into new markets (e.g. light rail and aerospace).	30%
AIN (SME)	Surface coating & Tooling tech.	Additional sales due to the demand on high performance tools, especially, new business relating to the coatings developed for hot stamping dies for the manufacture of panel components.	10~20%
MAR	Aluminum	MAR will have deeper knowledge about	25-45%

(SME)	specialist	Aluminium alloy selection for different applications and will support OEMs in choice of Aluminium Alloy grade. This gives increased customer base and increased sales.	
PLA (SME)	Tool manufacturer (casting)	Additional sales as a manufacturer of HFQ specialist tools. Opportunity to provide casting for large hot stamping tools for decreasing friction and extended lifetimes.	15~25%
TBZ (SME)	Tool-analysis specialist	Generate extra sales due to ability to help with design of tools for HFQed parts. Extra income from dissemination working with ITL.	20~25%
ANT (SME)	KBDS developer	Will have extra sales through meeting demands on the use of the KBES as a part of the design software of HFQ.	15~25%
DIG (SME)	Sustainable technology specialist	Income in providing advice on component design for HFQ. Extra income from market development in collaboration with ITL.	5~10%
ESI	CAE software provider	Extra sales of software due to the ability to model formability in hot and warm forming. Extend the knowledge to hot stamping of steel parts and extra sales on steel hot stamping software are expected.	5-15%
APT	Stamping equipment provider	Development of HFQ production systems. Will be able the first to offer an integrated production line for HFQ. Hope to share over 60% of the market on providing HFQ production lines in next 15 years.	> 20%
CRF	World-class automotive industry	Opportunity to take HFQ into true mass market sales of volume vehicles and be first mover in C segment vehicles. First mover for exploiting applications for lightweight trucks, buses and lightweight vehicles.	5-10%

HAI	EU leading aerospace Co.	Materials saving and cost reduction opportunities for aerospace customers. Potential weight reduction by using sheet metals.	5%
Universities	Higher education, research and knowledge exchanges	Besides sharing in royalties, universities will benefit from the innovation by providing services in design and analysis of material, processes, tools and machinery. Being non-profit organisations, the main motivation for participating in the project is to enhance their status in the industrial research community and to help EU SMEs.	2~3%

5. The address of the project public website, if applicable as well as relevant contact details.

The project website can be found on www.locolite.net/ProjectArea1/home with additional information regarding recent developments of HFQ found on the LoCoLite twitter page: **@locoliteeu** and Youtube channel: LoCoLite EU Project.

The project co-ordinator, Prof. Jianguo Lin can be contacted through the email: jianguo.lin@imperial.ac.uk or through the telephone: +44 20 7594 7082.

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