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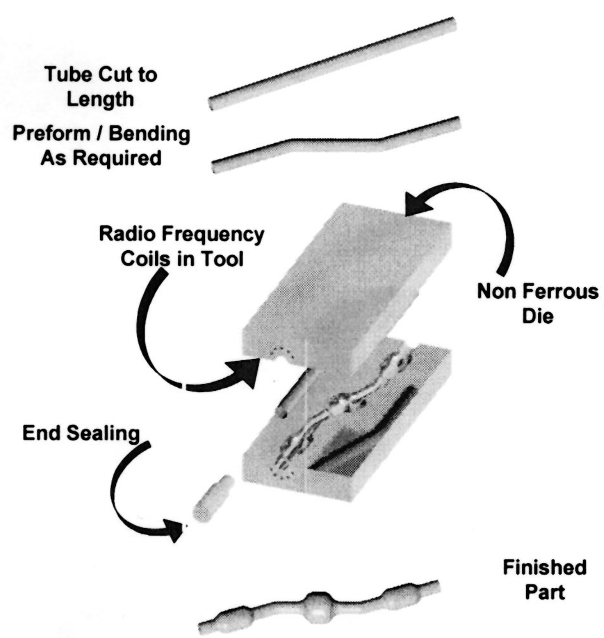
ABSTRACT

Hot Metal Gas Forming is an innovative metal forming technique with the potential to leapfrog conventional metal forming techniques of structural steel components for automotive and aerospace industry. HMGF is an outgrowth of superplastic forming (SPF) and hot blow forming (HBF) techniques that the aerospace industry developed to form aluminum and titanium structures. The goal of this program is to develop the HMGF process and prove its production readiness for wide spread use in the Automotive and Aerospace industries by proving process robustness. An early process concept is shown below.



INTRODUCTION

THE TEAM – As with any new or refinement of a current process the vision was to accomplish a specific goal. Initially it was to develop a less expensive tubular metal forming process. As the HMGF process was visualized additional benefits were discovered as a result of the process, like additional flexibility, reduced tooling costs and finally faster cycle times. The vision was developed in conversations with many trusted friends, notably George Pfaffmann of TOCCO and Xin Wu of Wayne State University. As the vision developed it turned into process concepts and then too technical challenges. This process could have been developed in a isolated research laboratory, however the depth of knowledge required in many individual fields and the complexity of the tasks would have killed the program under its own weight. Instead to accomplish the many tasks a team was assembled, with each of the individual team members being experts in their own individual fields.

Atlas Tool	(Transfer Technology)
Autodesk	(Design and Tooling Software)
Reynolds Aluminum	(Material Expertise – Aluminum)
Battelle	(Research Institution)
Boeing Aircraft	(SPF - Technology)
Daimler/Chrysler	(Product Performance Standards)
Copperweld	(Tube Rolling Technology
Erie Press	(Equipment and Press)
Ford	(Product Performance Standard)
Hydrodynamics	(Tooling / Process Technology)
Lamb/Modern Prototype	(Tooling / Process Tech)
Ispat (Inland Steel)	(Material Expertise – Steel)
Rockwell / Allen Bradley	(Controls Technology)
Sekely Industries	(Tooling Expertise)
TOCCO	(Induction Heating Expertise)

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Tower Automotive	(Manufacturing Requirements)
Troy Design	(Product and Tooling Designs)
Wayne State University	(Research Institution)

OVERVIEW OF THE PROGRAM

An evaluation of the make-up of cars and trucks reveals that the body structure is made out of tubular sections. Some of these tubular sections may not be recognizable at first, because their shapes are not uniform in size or shape or their true function is hidden. Up to the last few years the only approved material processing method that was allowed to make these sections were conventional stampings combined with spot welding (used primarily for body shells, BIW), or stampings and MIG welding (used primarily for engine cradles and frame assemblies).

Currently a more popular manufacturing process called tubular Hydroforming has been introduced and accepted by the automotive industry to make these tubular sections. We have found many cases where the value of the new (tubular) design (hydroformed) is greater than the value of the old (conventional stamp and weld) design, however we have also found cases where it was the other way around. Which process is capable of producing the more “value”, component is primarily dependent on a variety of items. First of which is how well does the new (hydroformed), designed component replace the function of the currently designed component. Second how well does the new component tie in or assemble to “the rest of the structure”. Third is its weight to performance Raito and finally the total cost picture. All of these four items have to be evaluated when determining the value or efficiency of a component or assembly.

BACKGROUND INFORMATION – Hydroforming is a process is that uses water and pressure to form material (aluminum or steel), into a shape determined by the shape of a die cavity. This process has been demonstrated to be very reliable and dimensionally accurate for both tubular sections (primary high volume application so far) and single sheet Hydroforming. It should also be noted here that extensive research work has been done around the world in duel sheet Hydroforming. This process uses duel blanks that have been laser welded together around the outside to create a fill cavity and using either oil or water mixture as the fill / pressure forming mechanism to form the duel sheet blanks to fill the die cavity.

Hydroforming in general (tubular, single sheet and multi sheet) are generally slow (22 to 50 sec/[part), has high capitol costs associated with it (in both the hydraulic press, intensifier equipment and tooling), and can place undesirable strain in the material at uncontrolled locations and is shape or design constrictive.

Even with these restrictions the automotive vehicle OEM’s have found many, many applications for these hydroformed tubular sections and have designed in components using Hydroforming as a tubular manufacturing shaping process.

The process of Hot Metal Gas Forming was not designed to replace Hydroforming, but was originally conceived as a low cost alternative to Hydroforming. As the vision was developed the focus areas were expanded to process speeds, capitol equipment costs, and improving the product strength to weight Raito through heat-treating.

PROJECT NARRATIVE

PROBLEM STATEMENT – Vehicles of the twenty-first century must be designed and manufactured using appropriate technologies to satisfy customers who expect vehicles with:

1. Satisfactory performance, size, utility, and comfort features
2. Improved safety, fuel economy, and significantly lower pollution characteristics
3. Overall improvements in noise, vibration and handling.
4. No increase or even decreases in purchase price

Automobile companies are forced to reduce the cost of these vehicles every year in order to expect to retain reasonable profit margins. There are only two ways to increase a vehicle’s performance and reduce cost at the same time.

1. Through more efficient vehicle designs (which reduces component material usage both in amount required and in engineered scrap), to meet customer demands
2. Through more efficient use of the capitol (equipment and tooling) and people used in the production process to produce the desired component to the specified design.

Advantages of a more tubular structural vehicle designs include:

1. Estimated lighter vehicle weight by 5 to 15%
2. Increased design flexability for the OEM’s designers and Engineers
3. Generally 5 to 10 % less expensive than conventional stamp and weld assemblies
4. Noise, Vibration and handling characteristics
5. Better crash performance (bending and torsion rigidity)
6. And is more dimensionally stable, especially in comparison to MIG welded assemblies

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CURRENT BEST PRACTICE (TUBE HYDROFORMING) – Currently, the best method to produce tubular structural components is hydroforming. This method has the following steps.

1. Tubes are rolled from steel material with specific initial strength and elongation. It is cut to length and pre-bent into a shape appropriate for finished part.
2. The pre-form (or blank) is mechanically loaded into the tooling of a hydraulic press (typically 3500 to 8000 ton capacity).
3. The tube ends are sealed and the tube is filled with water / oil mix. The internal pressure is raised (typically 20,000 to 80,000 psi) to expend the tube and ensure its dimensional integrity
4. Holes are pierced and pressure is released. The die is opened, water is drained, and the part is mechanically removed.
5. Secondary operations for hole cutting (not obtainable durring the hydroforming process) and end trimming are preformed.

Total cycle time for hydroforming is 22 to 50 seconds. The limitation of this process is the maximum strain rate of the material at ambient temperatures

Hydroforming work centers are extremely large and expensive because of the internal pressures required for the process.

SCIENTIFIC AND TECHNICAL MERIT – The goal of the Hot Metal Gas Forming (HMGF) program is to increase the competitiveness of U.S. automotive manufacturers and associated suppliers of structural components through a new process technology. HMGF has the potentional to offer lower product piece cost, lower tooling cost, faster time to market, and lower vehicle weight.

Hot Metal Gas Forming achieves these benefits through the unique characteristics of this new process. Lower product cost results from lower capital investment in machine tools. Less costly machine tools are required because the process operates at lower pressures than conventional metal forming. Lower tooling cost and faster time to market result from innovative tooling designs that accommodate high temperatures but are not subject to the stresses of traditional metal forming tooling. Reduced vehicle weight results from materials that have higher yield strength that is tailored to match the application. This tailored yield strength material is possible because of new post processing techniques.

Specifically the HMGF program seeks to reduce product piece processing cost by 50 %, reduce the time to build metal forming tooling and its cost by 40%, and reduce overall chassis weight by 20%.

Hot Metal Gas Forming is an innovative metal forming process with the potential to offer significant cost savings over conventional stamp / weld techniques and the process of tubular Hydroforming. The HMGF program will enable U.S. suppliers to leapfrog the current technology of Hydroforming metal processing technology, which primarily resides in Germany.

Tubular structures are currently produced using Hydroforming techniques. Tooling costs for hydroformed parts are approximately the same as stamping (at annual volumes of 200,000 to 400,000 units). Current production methods, however, have the following disadvantages:

1. Capitol cost are 200 to 500% higher than conventional stamping
2. Process speeds are slow (22 to 50 sec per part)
3. Design restrictions caused by the Hydroforming process; limit the vast potential of tubular structures. Generally any size or shape changes over 10% of the original tube diameter will require a secondary hydroforming bulging operation or a material annealing operation or both.

OPPORTUNITY – Hot Metal Gas Forming overcomes many of the disadvantages of current techniques. HMGF is an outgrowth of an internal study to concept a process that better matches the business drivers of reduced cycle time and lower capital investment.

The concepts for HMGF are based on parts of the following current technologies:

1. Superplastic forming (SPF) techniques. This technology was developed by the aerospace industry to form aluminum and titanium structures. SPF has excellent elongation characteristics needed to form complex shapes at low pressures utilizing ceramic tooling. However, SPF is extremely slow and not well suited for expanding common carbon steels.
2. Hot blow forming (HBF) techniques. This technology is used in the plastics industry, in high volume environments. However, HBF is used with conventional tooling steels, which will not work when forming steel.
3. Electrical resistance heating (ERH) techniques. This technology is widely used in a variety of applications, from welding to heat treatment.
4. Induction heating techniques. This technology is widely used in the automotive for tempering, annealing and fast heating of ferrous materials.
5. Die quenching and tempering has been used for many years to process material to have very high strength material properties.

The key steps of Hot Metal Gas Forming include:

1. Welded tube is made from steel sheet under a controlled rolling schedule. The material is formed to a blank tube and pre-bent (if Req.) by conventional tube bending techniques
2. The preformed blank tube is preheated using resistance heating
3. The part is then preformed (to the die cavity shape – as required)

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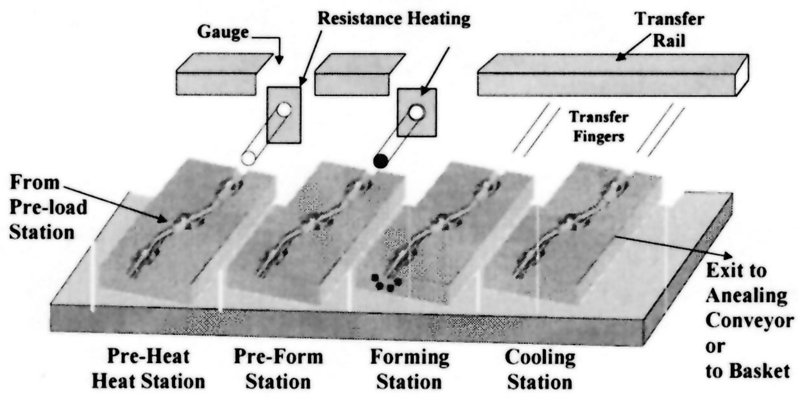


4. The pre-heated blank is placed into the HMGF station in the die. The tube receives a secondary heating to the forming temperature (about 1800 Deg F). The tools have imbedded induction-heating coils. The part end openings are sealed and the blank is expanded utilizing gas pressure (300 to 1000 psi) to expand the tube and thus fill the tooling cavity
5. The formed part is cooled at a controlled rate sufficient avoid the formation of undesirable microstructures and enhance mechanical properties

RESEARCH AND DEVELOPMENT OBJECTIVES – The objective of the HMGF program is to improve competitiveness of participating automotive suppliers through the development of a new metal forming process technology. Specific objectives include:

- Reduce the processing cost to produce structural vehicle components by 50%
- Reduce the time to build and the cost to build metal forming tooling by 40 %
- Reduce overall structural vehicle component weight by 20%

In order for HMGF processed to achieve these benefits, new technology innovation is required.

This new process is a hot forming process that requires new kinds of tooling that can incorporate induction heating elements for localized heating, support moderate forces, and provide wear resistance. Methods need to be developed to provide electrical connections through the tooling to the induction heating elements. This new tooling can be developed using aluminum oxide material that is either cast or printed using a stereo lithography technique.

The HMGF process, itself, needs to be characterized. This new process will require dynamic sequencing of the temperature and gas inflation pressure over time.

The HMGF process will develop new post processing methods. These new methods will require closed loop control of temperature and die water quenching to temper the formed product. This tempering could increase t he yield strength of selected materials from 35 ksi to 120 ksi. Localized tempering will produce a tailored multi-strength formed product. This type of product, in an automotive application, would respond like a much more complex multi-piece assembly or tailored tube.

In order to meet these objectives, we have defined four major projects, or team areas – a listing with their mission statements and leaders are listed as follows

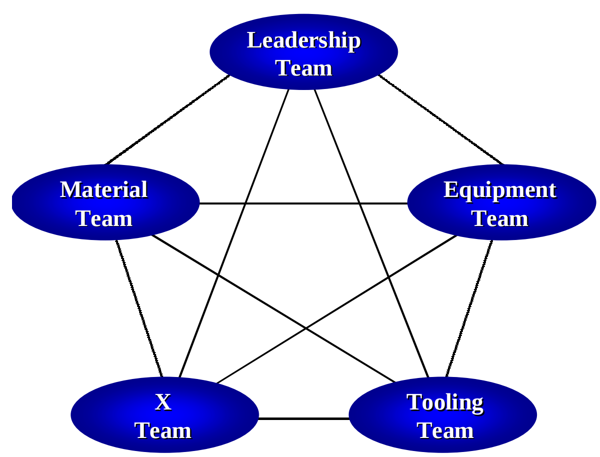
Material Team – Leader Phil Smith (Reynolds Metals)
Mission – To identify, develop, test and categorize material (aluminum and steel), for use in the HMGF process

Tooling Team – Leader George Pfaffmann (TOCCO)
Mission – To design, build and assist in tryout, forming tools for Phase II and Phase III of the program

X-Team – Leader Harry Singh (Hydrodynamics)
Mission – To establish deliverables in process, robustness and product / material characteristics.

Equipment Team – Leader Bill Dykstra (Tower)
Mission – to design, build and test equipment and peripheral equipment and necessary controls to enable the HMGF program to be a success

Leadership Team – Leader Bill Dykstra (Tower)
Mission – to coordinate and guide the efforts of the individual teams



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In each project, the approach involves extending the state-of-the-art of existing technologies to the next generation of metal forming and materials technology.

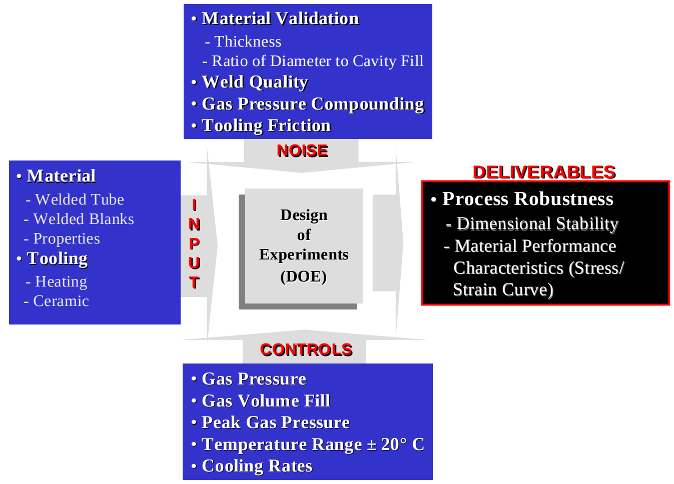
CORE INNOVATIONS – The innovative aspects of HMGF that distinguish this technology from state-of –the-art metal forming techniques, such as stamping/ welding or hydroforming include:

1. Using moderate temperatures to increase the formability of the steel without excessive grain growth.
2. Taking advantage of moderate forming pressures to utilize low cost tooling and smaller machine tools.
3. Integration of part heating into the forming tools to reduce cycle time.
4. Controlled tempering to yield parts with locally tailored yield strengths

The HMGF process further depends on new technical innovation in the areas of ceramic tool design with imbedded induction heating elements, existing and new material formulations, development of the HMGF process itself, and controlled cold quenching techniques. Specifically, they include:

1. Development of HMGF cast-able ceramic forming dies which incorporate high-frequency induction coils. The coils permit heating of the work piece at a high rate. This feature reduces the process cycle time and minimizes re-crystallization and grain growth phenomena that reduces material strength properties.
2. Sheet steel formulation including high carbon steel, high strength-low alloy steel and duel phase steels, through thermo-mechanical processing techniques to control grain size and microstructure of secondary phases.
3. Methods of heating and cooling of the workpiece using microprocessor feedback control. Essentially, this becomes a “smart” metal post processing station / forming die

TECHNICAL RISK AND FEASIBILITY – The program envisioned on Hot Metal Gas Forming carries a high level of technical risk. The successful development of HMGF will require major developments in materials technology (both for the forming dies and steel sheet) and metal forming technology. The key benefits of this technology are expected to be flexible design changes using low-cost, readily fabricated tooling and new design opportunities for lightweight structural components.



The key elements of technical risk associated with this program include:

1. Ceramic die life – Although ceramic dies have been used for superplastic forming of aluminum parts in the aerospace industry, these materials have a useful life of only several hundred parts. Die life is limited primarily by cracking induced by thermal cycling. New graded ceramic materials are expected to offer major improvements in thermal cycling resistance, but further work is needed to achieve these results in actual forming operations.
2. Steel formability – Conventional cold rolled plain carbon steel sheet used for welded stampings is likely to have sufficient ductility for any zero expansion operations needed when the product design only calls for constant cross section shape with no change. We expect that improved formability will result from a combination of hot forming techniques in conjunction with modifications to the steel microstructure or composition. Achieving major increases in formability using economical steel manufacturing practices is a significant technical challenge.
3. Process control – The HMGF process will require advances in the ability to handle hot parts at high production rates. Also, the use of embedded die heating with dies equipped with sensors/controls to provide feedback control of the condition of the workpiece is a significant advance for metalworking operations.

High strength steel is preferred for automotive structures, but is rarely used due to limitations of today’s forming technology. For bending a thick sheet (~3mm) low strength AKDQ steel is needed for both stamping and hydroforming processes. However, high temperature

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forming it is not sensitive to carbon and alloy constraints. This provides a great opportunity for using high strength steels.

RESEARCH AND DEVELOPMENT PLAN

Phase I

1. Utilizing a Tensil System (TS) at WSU, determine forming limits and process parameters of selected materials (Aluminum and Steel)
2. This phase of the program will determine process parameters/equipment capabilities required for phase II

Phase II

1. Design, build/modify and launch the Laboratory Forming System (LFS).
2. Utilizing the LFS, determine forming limits and process parameters of experimental shapes and/or selected materials (Aluminum and Steel).
3. Determine experimental shapes – build tooling for and tryout lab forming testing tool and determine forming limit parameters for selected materials
4. Determine process parameters/equipment capabilities required for prototype production forming system

Phase III

1. Design,build and launch the Prototype Production forming System(PPFS) to validate process robustness
2. Desing, build and tryout forming tooling for the (PPFS)
3. Determine process parameters for various materials (Aluminum and Steel), process forming capability, post processing capability and production process validation

RESEARCH OBJECTIVES

Goal 1

Verify feasibility of the process (To prove out HMGF techniques using simple laboratory tooling)

Goal 2

To build a prototype production system using tooling, material and processing techniques learned in this program to prove process robustness and extablish production costs (tooling and piece) / 300 piece run.

Goal 3

To prove out low temperature superplastic techniques and to conduct DOE experiments.

In-situ thermal treatment to achieve an improved mechanical properties of the parts.

GENERAL INFORMATION – This is a three-year effort that brings key automobile companies, structural component suppliers, material suppliers, and tooling suppliers together with academia and research institutes for new process and materials development.

The Hot Metal Gas Forming process seeks to remove these constraints, by adding a third dimension to the process, HEAT. Specifically this process seeks to fulfill the Original Equipment Manufacture's for both ground vehicle transportation and airplane manufactures needs in three ways. First it seeks to follow in the foot steps of tubular hydroforming by performing the same processing tasks that tubular hydroforming is capable of performing but at reduced cost. Secondly, the program seeks to surpass the formability that is currently available in the cold forming of materials. Third, the very fact that the forming cycle is completed, the part is already preheated for free, and allows the user to choose a multitude of post processing techniques, depending on the material properties that the product designer would like out of the component.

The process also seeks to improve the material to strength / weight ratio, increase the flexibility of the structural design and by introducing more capable manufacturing processes at a low cost-to-performance ratio. The Hot Metal Gas Forming technique can greatly widen the material formability window, thus release the design constraints of current process used in the manufacture of components today.

HMGF process consists of

1. Utilizing inexpensive low-cost 1008-1010 steel to product low cost tubular sections, and high-strength duel phase steels with up to .12C for producing products with high amounts of design flexibility and extruded and flat sheet aluminum products,
2. "Bulge forming", of the hollowed parts in a ceramic die cavity with embedded heating coils, with regional temperature profile and time controls, and

The major advantages of this process are its high formability limits. We are targeting to achieve greater than 50% elongation at a strain rate of 10-1/s in steel and 100 % elongation at a strain rate of 10-1/s in aluminum. In comparison to conventional superplastic forming, which is capable of much elongation, it is also formed over a much longer period of time of 10-3/s

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The application of cast-able ceramic dies used in this technique opens another domain of the manufacturing opportunity for rapid processing and reduced tool costs and lead-time.

Hot forming also reduces time and increases process flexibility but more importantly reduces capitol equipment costs

The application of cast to shape ceramic dies used in this technique opens another domain of manufacturing opportunity for rapid processing and reduced tool costs and lead-time.

An industry joint venture and research institution team has been formed under an US-NIST-ATP funded program called Hot Metal Gas Forming for developing this new manufacturing technique.