Future Trends in Metal Forming—Equipment, Materials and Processes in Automotive Applications

D. Hitz and R. Duggirala

Global competition in the automotive market has made a significant impact in the materials, processes, tools, and equipment used to make components. Steels are being replaced by other materials, such as aluminum, composites, and plastics, that meet the demand for a higher performance per weight ratio. From a processing viewpoint, the customers demand production of parts to near-net shape with little or no machining. Competition in business depends on understanding the needs of the customer in the coming years in the area of metal forming. A workshop was conducted using a novel approach to address the above issue. This presentation describes the approach and the results of the study.

Keywords
automotive applications, automotive processes, trends metal forming

1. Introduction

GLOBAL competition in the automotive market has made a significant impact in the materials, processes, tools, and equipment used to make components. In the past, primarily steels (carbon and alloy) were used to produce automotive components. The customers of today, however, demand significant gains in performance and reduction in the weight of components. This has resulted in a trend toward the use of lighter materials providing higher performance per weight ratios for automotive components.

The steel components have been produced by conventional processes, such as forging, casting, rolling, and machining. However, from a processing viewpoint, the customers demand production of parts to near-net shape with little or no machining. This demand has resulted in tighter process controls, new processing methods, and tools to enable near-net shape manufacturing.

The requirements of the customer change with time, and the ability to stay competitive and in business relies on forecasting and recognizing the needs of the customer in the future. In an effort to clarify the needs of the customer in the coming years in the area of metal forming, a workshop was conducted using a novel approach. This presentation describes the approach and results of the study. The impact of the trends in customer needs on machining equipment is also presented.

2. Description of Approach

The objective of our study was to identify the probable evolution of metal forming technology, excluding stampings, as it will occur in the world over the next fifteen years. It was believed that this information, when combined with our product technology plan, would enable us to understand better the specific competencies our manufacturing engineering department must maintain, grow, or procure. The "storyboard process" was used to obtain the above information.

D. Hitz and **R. Duggirala,** General Motors Corporation, M/S99, 3900 Holland Rd., Saginaw, MI 48601-9494, USA.

2.1 *General Process Description*

The first step in the process consists of establishing a "circle of expertise," who when put together could create a more synergistic and holistic vision of a given topic. It is critical to get people from diverse backgrounds relating to the topic to prevent a narrow opinion or vision. For a global opinion, participants from different parts of the world may be required.

The selected participants meet at a given venue. Completing the session, for most topics, takes one working day. Typically, the first half day is spent on group orientation and development of the "events and drivers" sections, and the second half of the day is spent developing the "results" from the drivers (in this case, the effects on metal forming technology over time).

Using 3 by 5 in. cards, participants write down their ideas relative to a given topic. The ideas are collected as they are written and read aloud to stimulate further ideas from others. No criticism is allowed in the first round of idea collection. All cards are pinned or taped to a "storyboard wall" for viewing and reviewing. A session administrator(s) then groups the cards into quantifiable categories for easier reading and editing. The cards under these categories then may be prioritized. New categories may be added or deleted, and cards may be moved from one category to another based on which category better fits the

The Following Companies Participated in the Storyboard Process:

- **Saginaw Division, General Motors Corporation -- Co-Sponsor**
- **The Ohio State ERC -- Co-Sponsor**
- **National Center for Manufacturing Sciences**
- **Erie Press Systems**
- **Domestic Cold Header Manufacturer**
- **European Press Manufacturer**
- **Two Domestic Steel Producers**
- **Asian Automotive Transplant**
- **Asian Metal Forming Company**
- **Lubricant Supplier**

Fig. 1 List of companies that participated in the storyboard process classification for a given card. At the end of the session, the "storyboard wall" is captured, and the results are synthesized and published.

2.2 *Fifteen-Year Metal Forming Vision Development*

We recognized that Saginaw Division was too parochial to pull together an accurate global view of future trends in metal forming. Therefore, we interfaced with The Ohio State University, Engineering Research Center for Net Shape Manufacturing (ERC) to utilize our combined contacts to make the participant companies as global as our time constraints allowed. The companies that participated are listed in Fig. 1. We utilized a two-step "storyboarding" technique to promote an unconstrained, free flow of ideas.

- *Step 1:* We divided the fifteen years into three segments, 5 years each, and addressed the question, "What are the events and drivers that occur in the world that would cause metal forming users to want to change their metal forming process or seek alternative solutions?"
- *Step 2:* Again within the same three segments of five years each, we addressed the question, "Given that the above events and drivers occur, what changes would they manifest in the metal forming world?"

After the storyboard session, the information generated was compiled and issued to each of the participants to prioritize in terms of the likelihood that the specific event or change to the metal forming world would actually happen. Figure 2 shows the responses to a given event and/or driver as filled out by one of the participants on the product end in the 0 to 5 year time frame. Figure 3 shows the tally of the responses of participants on equipment and/or processes in the 6 to 10 year time frame. The following information describes trends as prioritized by the participants. It does not attempt to quantify the trends. Once again our objective was to identify trends in the evolution of the metal forming environment so that, when combined with our product technology plan, they would allow us to manage our manufacturing engineering technologies better.

Potential Results in Metal Forming Arena—0-5 Years

	Cannot rate	Unlikely	Somewhat unlikely	Neutral	Somewhat likely	Likely
Product (of metal forming technology)						
More use of high strength alloys in forming						X
More part inspection to guarantee "zero" defects to customer (in process)			X			
Use of boron in steel, in place of some alloy, to maintain hardenability, improve formability				X		
Use of SeTe to improve machinability without degrading formability				X		
Better surface quality hot rolled bar through improved mill processing				X		
Sheet metal (formed) components for transmission (replace wrought/PM)					X	
Carb → ind. harden requiring process with control of decarbing						X
Decarb-free part from net shape form (need)			X			
Use of stronger steels—lighter weight (i.e. size) carry same or more load					X	
Steel chemistry + processing → final properties (e.g., warm form in 2-phase region)					X	
Steel "tolerances" (size, surface, etc.)					X	

Fig. 2 Response sheet showing drivers/events identified and entries

Potential Results in Metal Forming Arena—6-10 Years

	Cannot rate	Unlikely	Somewhat unlikely	Neutral	Somewhat likely	Likely
Equipment/Processes						
Laser or water jet cutting system of axial flash for close die forging	7	2	7	3	2	2
Computer controlled setups and changeover	2		1	7	8	5
Semi-solid metal forming commercially viable for ferrous materials	4	4	3		6	
Elimination of phoscoating → lube at point of forming for cold forming	4	2	2	4	9	2
On line dimensional control with non-contact sensors	4		2	3	12	2
Better process design results in less annealing steps	1		1	3	14	4
Flashless hot forging	2		3	2	12	4
Better cut-off quality and accuracy				1	10	12
Sensor/computer diagnostic systems on presses will predict cycles until tool mechanical failure in press	4	1	4	4	6	4
More prelubricated or plated billet feeding of automated multi die processes	5			6	11	1
Cellular forming equipment (i.e., hyd. pressure orbital forming, etc.)	4		2	8	9	
Warm squeeze (multiple action) forming on 1 station	6		1	6	9	1

Fig. 3 Tally of responses of participants to a set of drivers and/or events

1. Forming Processes

1.a. Five year time frame

- **Cold ring rolling of axi-symmetric parts**
- **Hot/warm swaging of shafts, etc.**
- **Warm forming and temper warm forming parts fully hardened for use**
- **Flashless hot forging**
- **Multi-action forming technology (single-station process for complex parts)**
- **Warm forming including warm sizing**
- **Warm forming in closed dies**
- **Semi-solid metal forming commercially available for aluminum**
- **Using existing heat for additional treatments after warm forming**
- **Controlled cooling after forging to obtain mechanical properties**
- **Warm form/cold form technology cross-overs producing effective net shapes**
- **New cold forming lubricants, Boron, Boric acid, Polymers**
- **New or converted forming systems for aluminum**

Fig. 4 Trends in forming processes in the five-year time frame

1. Forming Processes

b. Six to ten year time frame

- **Elimination of phoscoating --> Lube at point of forming for cold forming**
- **Better process design results in less annealing steps**
- **Flashless hot forging**
- **More prelubricated or plated billet feeding of automated multi-die processes**
- **Warm squeeze (multiple action) forming in single-station**
- **Thermal energy recovery system for warm/net form parts**

Fig. 5 Trends in forming processes in the six- to ten-year time frame

2. Process Tolerances/Reliability

a. Five year time frame
- Reduced tolerances in hot forging (by half or less)
- Increased process reliability
- Greater specification and part making flexibility
- Increased process reliability, decreased inspection

b. Six to Ten years time frame
- Laser or water jet cutting system of axial flash for closed die forging
- On line dimensional control with non contact sensors
- Better cut-off quality and accuracy
- Forming tolerances equivalent to today's grinding
- Precision cut mults (billets) -- continue to decrease weight variation of each mult
- More net shape alloy parts used as formed
- Further reduction in hot forging tolerances

Fig. 6 Trends in process tolerances and/or reliability in the five- and ten-year time frames

3. Equipment Automation/Enhancements

a. Five year time frame
- Expanded use of tonnage "signal 20" during forming cycle to control process
- More complex automated equipment
- Computer controlled rapid part changeover
- More sensors and diagnostic systems on presses to help operators optimize process
- Sensors/signature analysis, machine monitoring and control
- Machines becoming easier to operate (with less skilled labor)
- Increased machine cost due to automation
- Development of handling equipment for net shape forgings
- Multiple actions in both horizontal and vertical direction
- More responsive hydraulic servos and controls
- Process monitor including automatic adjustments
- More automated machine fault indicators

Fig. 7 Trends in equipment automation and/or enhancements in the five-year time frame

3. Equipment Automation/Enhancements

b. Six to Ten years time frame
- Computer controlled setups and changeover
- Cellular forming equipment (e.g., hydraulic pressure, orbital forming, etc.)

Fig. 8 Trends in equipment automation and/or enhancements in the six- to ten-year time frame

4. Forming equipment maintenance/reliability/productivity

a. Five year timeframe
- Development of predictive maintenance of machines
- Equipment PM replace components prior to catastrophe
- Use of manuacturing cells for specific product lines
- Accurate shearing system allowing closed die forming with hot rolled material
- Optimize equipment and tooling to obtain more robust and better processes
- Horizontal forming equipment for ease of installation and serviceability
- More closed loop process controls
- More accuracy and repeatable service-life

b. Six to Ten year timeframe
- Sensor/computer diagnostic systems on presses will predict cycles until tool mechanical failure in press

Fig. 9 Trends in forming equipment maintenance, reliability and/or productivity in the five- and ten-year time frames

5. FORMING TOOLS

5a. Five year timeframe
- Ability to preload to tooling to higher levels
- Increased off-line setups for higher operating efficiencies
- Tooling with cooling and heating systems for hot/warm forming processes
- Develop die wear monitoring systems
- Increased knowledge of lubrication conditions using standardized testing
- Simplified tool design for easy manufacturing/low cost
- Tooling designed for quick change
- Flexible/interchangeable tooling for small lot production
- Disposal of processng lubes more expensive
- P.M die steel - greater use

Fig. 10 Trends in forming tools in the five-year time frame

5. FORMING TOOLS

5b. Six to ten years timeframe
- Improvement in tooling materials for lower cost and increased life
- Localized lubrication in tools to reduce use of lubricant
- New methods of building up worn die surfaces
- Special coatings (to replace lubricants)
- Development of high strength die material for closed die hot forging of complex parts
- Sensing will determine impending tool failure
- Fast change tools between different types of forgings (standard tool holders)
- Expand formed dies for increased strength

Fig. 11 Trends in forming tools in the six- to ten-year time frame

6. C.A.E./Expert Systems

a. Five year time frame

- Prediction of fatigue life and improving tool-life via C.A.E design
- Integrate CAD/CAM/CMM on complex geometry
- Near net and/or net shape process design through modeling and simulation
- Automatic generation and regeneration of mesh for F.E.A.
- Use of FEA on production machine components
- CAE will help improve die life
- Reduced time to develop tools through CAE
- Computer software to design optimum product (gears) and manufacture tooling
- Automated design of forgings and process sequence
- 2D/3D metal flow simulation
- Rapid prototyping of parts (computer generated)
- Capture forming expertise of retiring engineers in expert systems (database) use for process design and diagnostics

Fig. 12 Trends in CAE and/or expert systems in the five-year time frame

7. Material

a. Five year time frame

- More use of high strength alloys in forming
- Use of Boron in steel, in place of some alloy, to maintain hardenability, improve formability
- Use of Se, Te to improve machinability without degrading formability
- Better surface quality of hot rolled bar through improved mill processing
- Sheet metal (formed) components for transmission (replace wrought/PM)
- Induction hardening requiring process w/control of decarb
- Use of stronger steels for higher performance/weight ratio
- Steel chemistry and processing control to produce final properties (e.g. warm form in the 2-phase region)
- Steel tolerances (size, surface, etc.) will become tighter
- Steels required based on properties rather than chemistry
- Demand for increasing consistency of material formability from "lot to lot"
- Trend to higher strength steels means more alloy- higher raw material cost

Fig. 14 Trends in materials in the five-year time frame

3. Results of Study

The trends presented here are based on responses of somewhat likely or likely against a proposed item in the survey. The results of the study have been summarized as trends at time frames of 5, 10, and 15 years in the following categories:

1. Forming processes
2. Process tolerance and/or reliability
3. Forming equipment automation and/or enhancements
4. Forming equipment maintenance, reliability and/or productivity
5. Forming tools
6. Computer-aided engineering (CAE) and expert systems
7. Material
8. Education
9. Other

The results of the study within the 5 and 10 year time frame only are presented in the following sections. Figures 4 through 18 describe the trends in the above categories.

6. C.A.E./Expert Systems

b. Six to ten years time frame

- Process simulation systems will go from billet to finish machined part. Systems will provide
  - forming tool and die
  - machining tools
  - heat treat tools
  - optimized process
- Increased utilization of simulation systems and neural networks will lead to design of more robust forming process
- 3D F.E.M analysis will help to form helical gears to net-shape

Fig. 13 Trends in CAE and/or expert systems in the six- to ten-year time frame

7. Material

b. Six to Ten years time frame

- Use of aluminum forgings in car
- Reduction in number of steel grades specified from O.E.M
- Expand use of formed bearing steels and stainless steels
- Semi-solid forming components from metal matrix composites
- Aluminum-Si-Carbide composites are used as forgings and castings
- More complex geometry's forgeable due to increased formability of billet material
- Acceptance of continuous cast steel for virtually all applications
- Decrease of machinability as the leading material characteristic
- Increased use of magnesium forgings in cars

Fig. 15 Trends in materials in the six- to ten-year time frame

8. EDUCATION

a. Five year timeframe

- Increased education of forming engineers to allow them to use simulation tools to perform process diagnostics
- Increased influence in direction of engineering education by industry

Fig. 16 Trends in education in the five-year time frame

4. Summary

Cars of the future should have higher performance, longer durability, and higher safety standards. They also should be pollution free, fuel efficient, lighter, stronger, and recyclable. These customer needs require the utilization of nonferrous alloys (aluminum, magnesium, titanium, etc.), plastics, composites, ceramics, and especially recyclables. Most of these materials will be formed into components and thereby necessitate the development of new forming processes. Forming equipment and processes have to be modified or developed to produce parts using these materials. These requirements tend to

9. OTHER

a. Five year time frame

- Technology exchange between companies
- More end user-steel producer cooperative design of material requirements
- More cooperative work between steel suppliers and manufacturers to improve formability of medium-high carbon steels.
- Users and metal/formers work together in design of product
- Preventive maintenance systems established
- Companies will become more specialized in formed products
- For net forming, manufacturing must meet product engineers prior to design
- Equipment manufacturer will be more involved in finish product design and development
- Multi party development programs -- all players in component chain -- with shared costs
- Continued expansion of supplier training for users
- Increased cooperative development programs between suppliers and users
- More part inspection in process to guarantee "zero" defects to customer

Fig. 17 Other trends in the five-year time frame

9. OTHER

b. Six to Ten years time frame

- Changes in operations management for higher machine utilization
- Steel supplied as individual mults versus bars which require shearing
- More efficient production planning systems
- Cooperative research for process development (material, lube, mach., user, etc.)
- Increased use of outside tooling designers
- Progress on funding specific process development (shared cost)
- OEM machine builder supplies maintenance & diagnostic services
- Better forecast of steel needs lowers inventory requirements and lower costs

Fig. 18 Other trends in the six- to ten-year time frame

emphasize the use of hydraulic forming equipment rather than mechanical because of more flexibility in control of the forming stroke. Customer requirement will be toward net shape and tighter tolerances requiring less machining. Therefore, machining requirements tend primarily toward finish machining.

The changing needs in material, forming methods, and subsequent heat treatment and processing, will significantly impact the machining requirement. Machining tools, equipment, and processes will need to be developed to machine the different materials, primarily as a finishing operation. The higher strengths of formed parts will require new machining tools and processes. New forming materials will also require the development of alternate materials and processes for cutting tools.

Any of the equipment and processes developed must embrace the concepts of lean and agile manufacturing. Primary emphasis will be on flexibility, modularity, low cost, and real time process control and optimization.

Trends indicate a more concurrent approach to part production with machining and machinability issues considered in conjunction with design, forming, and other manufacturing processes. Such approaches will be required not only by organizations producing parts, but also by those that supply equipment to provide the above functions. Collaborative efforts between equipment suppliers will enable quicker introduction of new materials for parts. Newer machining processes and machines developed will require training that may be required of the original equipment manufacturers (OEMs).

Sensors, diagnostic systems, and predictive systems will be implemented on machining equipment. Expert systems, neural network systems, and other computer-based tools will be applied to monitor the health of machining equipment and optimize the machining process. Maintenance schedules also may be prepared by such systems. The controls and systems built into the machining equipment will be more sophisticated. The storyboard process applied to metal forming may be applied to determining trends in other areas, such as machining and metal removal processes and equipment.

Acknowledgments

The authors acknowledge the contributions of Dr. Taylan Altan, The Engineering Resource Center at The Ohio State University and all of the participants and participating organizations in the storyboard process.