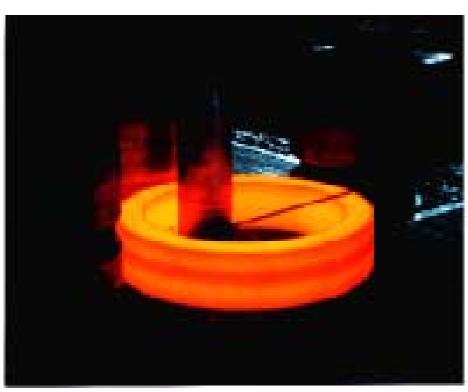
Forging Industry Technology Roadmap Update

Priority Research & Development Goals for the Forging Industry

Sponsored by:
Forging Industry Association
Forging Industry Educational and Research Foundation
and
U.S. Department of Energy
Industrial Technologies Program



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1 Executive Summary and Introduction

The North American forging industry has accelerated its pro-active, collaborative response to the challenges of intensified global competition, technological change, fluctuating economic and market conditions, and increased customer demands. The industry's long-term vision statement established aggressive technological goals in tooling, materials utilization, energy consumption, environmental performance, productivity, and quality.

The Forging Industry Technology Roadmap, published in November 1997, provided a tactical plan to overcome these challenges and ensure that the U.S. forging industry remains a world leader in customer-focused, efficient and cost-effective supply of high-quality components. The roadmap provides a tactical plan that ties the strategic targets contained in the Forging Industry Vision to the actual research portfolio that will be pursued by the industry through collaborative R&D and other mechanisms.

With many of the Technology Roadmap projects completed or active, the U.S. forging industry organized the Forging Industry Technology Roadmap Update Workshop to define the industry's new research priorities. The workshop was co-sponsored by the Forging Industry Association and the Forging Industry Educational and Research Foundation in cooperation with the U.S. Department of Energy's Industrial Technologies Program. This event brought together 41 experts, including representatives of forging companies and suppliers, academia and government agencies. As a group, they came to a consensus on the priority targets of technology barriers, critical research needs and opportunities for the forging industry.

The workshop consisted of two facilitated work group sessions in which participants explored the following areas:

- Die Materials, Die Surface Modification and Lubricants
- Simulation, Database Development and Closed Loop Control

Increasingly, U.S. forging companies are joining forces to work together on solving common problems. Collaborative partnerships among forging companies, suppliers, government agencies and research organizations will make the industry stronger as a whole and help individual companies successfully meet the competitive challenges ahead. George Mochnal, FIA's Director of Research and Education, expressed his enthusiasm for continuing the work that was started with the Forging Industry Vision and the Forging Industry Technology Roadmap.

2 Importance of Forging Industry

Forging has unique value among manufacturing processes. The industry is a key link between critical manufacturing segments—metal suppliers (both ferrous and nonferrous) and end user industries. Forgings are intermediate products used widely by original equipment manufacturers in the production of durable goods. They range in size from less than an ounce to more than 200 tons and are found in the machines, vehicles and equipment used to generate our industrial economy. Forgings are found in 20% of the products representing the Gross Domestic Product of the United States. The products of the forging industry are essential to the U.S. industrial economy, to its society, and to its national security.

Forging imparts advantages that few processes can duplicate. The industry's future is based on improving upon these advantages. The following are features of forging that make the process and industry so important to designers and users (specifiers) of components:

- Forgings can be manufactured from readily available bar stock,
- The products are fully recyclable,
- Forgings impart high strength and reliability to components,
- Forgings typically have relatively low life cycle costs.

Among the industries that depend on forgings are automotive and truck; agricultural machinery and equipment; valves, fittings, and petrochemical applications; hand tools and hardware; off-highway and railroad equipment; general industrial equipment; ordnance and marine; and aerospace.

Forging is a cost-effective way to produce net-shape or near-net-shape components. Virtually all metals can be forged, making an extensive range of physical and mechanical properties available in products with the highest structural integrity.

Forgings are used in high performance, high strength, and high reliability applications where tension, stress, load, and human safety are critical considerations. They are also employed in a wide range of demanding environments, including highly corrosive and extreme temperatures and pressures.

Most of the producers of basic metal (steel, aluminum, copper, titanium, and nickel) also produce forged product. Advances in these industries' technologies and efficiency have a direct bearing on the forging industry's ability to compete in the global market.

According to trade press estimates, in 2004 there were approximately 450 facilities at which the forging process is performed in the United States. More than half of these are located in five States: Ohio, Pennsylvania, Illinois, Michigan, and California. Another 20% of the nation's forge shops are in Texas, New York, Indiana, Wisconsin, and Tennessee.

Forging plants are primarily small or medium-sized companies. About 40% employ between 20 and 99 workers, and more than 75% have less than 250 employees. Among the facilities that forge components are independent, custom-forged part producers, original equipment manufacturers of a broad range of products, government research laboratories and military arsenals.

3 Forging Process

During the forging process, a metal workpiece is plastically deformed by pressing, squeezing, or hammering forces—usually at temperatures ranging from ambient to 1,500°C—so that it approaches its maximum theoretical density and the upper limits of the material's potential strength. The properties of the worked metal can be greatly enhanced by selecting the proper types and sequence of operations. The controlled process of deformation that takes place imparts exceptional metallurgical soundness and mechanical properties to the forging—structural integrity, impact strength, fracture toughness, fatigue life, and uniformity.

The manufacture of forged products can be carried out by several basic forging methods. The choice of method is determined by the quantity of parts to be produced, the characteristics of the material, and the configuration to be formed.

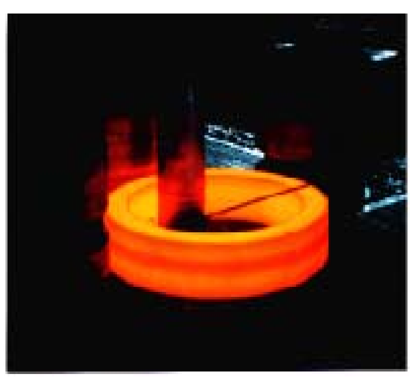
Impression-die forging, often referred to as closed-die forging, accounts for the bulk of commercial forging production. Most impression-die forging is performed at elevated temperatures and is known as hot forging. The optimum hot forging temperature depends on the material being forged. Also in the impression-die forging category are cold forging and warm forging processes.

Cold forgings are forged at ambient temperature. Cold forged parts are generally symmetrical and typically weigh less than 25 pounds, and because of their extreme dimensional precision and fine surface finish, they often need little or no further machining. Production rates are very high with long die life. In warm forging, the workpiece is heated above room temperature but well below hot forging temperatures.

Open-die forging differs from impression-die in that the metal workpiece is not confined laterally by impression dies. The process is typically associated with large parts, although part weights can range from a few pounds to 200 tons. The open-die forging process progressively works the starting stock into the desired shape, most commonly between flat-faced dies.

Ring rolling is a very cost and property effective process in which seamless rolled rings are forged in numerous cross-sectional shapes, ranging from several inches to over 20 feet in diameter. Rings can range in weight from one pound to more than 50,000 pounds, and are typically used in gears, bearings, couplings, rotor spacers, and components for pressure vessels and valves.

Closed Die



Ring Rolling

Open Die

4 Where Are Forgings Used?

• Automotive and Truck

In automotive and truck applications,forged components are commonly found at points of shock and stress. Cars and trucks may contain more than 250 forgings, most of which are produced from carbon or alloy steel. Forged engine and powertrain components include connecting rods, crankshafts, transmission shafts and gears, differential gears, drive shafts, clutch hubs, and universal joint yokes and crosses. Forged camshafts, pinions, gears, and rocker arms offer ease of selective hardening as well as strength. Wheel spindles, kingpins, axle beams and shafts, torsion bars, ball studs, idler arms, pitman arms, steering arms, and linkages for passenger cars, buses, and trucks typify applications requiring extra strength and toughness.

• Aerospace

High strength-to-weight ratio and structural reliability improve performance, range, and payload capabilities of aircraft. That's why ferrous and nonferrous forgings are used in helicopters, piston-engine planes, commercial jets, and supersonic military aircraft. Many aircraft are "designed around" forgings, and contain more than 450 structural forgings as well as hundreds of forged engine parts. Forged parts include bulkheads, wing roots and spars, hinges, engine mounts, brackets, beams, shafts, bellcranks, landing-gear cylinders and struts, wheels, brake carriers and discs, and arresting hooks. In jet turbine engines, iron-based, nickel-base, and cobalt-base superalloys are forged into buckets, blades, couplings, discs, manifolds, rings, chamber wheels, and shafts—all requiring uniformly high-yield tensil and creep rupture strengths, plus good ductility at temperatures ranging between 1,000 and 2,000°F. Forgings of stainless steels, maraging steels, titanium, and aluminum find similar applications at lower temperatures. Forged missile components of titanium, columbium, super alloys, and refractory materials provide unduplicated mechanical and physical properties under severe service conditions. Aluminum structural beams for boosters, titanium motor cases, nuclear engine reactor shields and satellite launch canisters of magnesium are used in the space shuttle program.

• Off-Highway and Agricultural

Strength, toughness, machinability, and economy account for the use of ferrous forgings in off-highway and heavy construction equipment and in mining machinery. In addition to engine and transmission parts, forgings are used for gears, sprockets, levers, shafts, spindles, ball joints, wheel hubs, rollers, yokes, axle beams, bearing holders, and links. Farm implements utilize key forgings ranging from gears, shafts, levers, and spindles to tie-rod ends, spike harrow teeth, and cultivator shakes.

• Ordance

Forged components are found in virtually every implement of defense, from rifle triggers to nuclear submarine drive shafts. Heavy tanks contain more than 550 separate forgings; armored personnel carriers employ more than 250. The majority of 155-mm, 75-mm, and 3-in. shells as well as mortar projectiles contain at least two forged components.

• Valves and Fittings

For valves and fittings, the mechanical properties of forgings and their freedom from porosity are especially suited to high-pressure applications. Corrosion and heat-resistant materials are used for flanges, valve bodies and stems, tees, elbows, reducers, saddles,and other fittings. Oilfield applications include rock cutter bits, drilling hardware, and high-pressure valves and fittings.

• Industrial, Hardware and Tools

Stationary and shipboard internal combustion engines include forged crankshafts, connecting rods, rodcaps, camshafts, rocker arms, valves, gears, shafts, levers, and linkages. Outboard motors, motorcycles, and power saws offer examples of the intensive use of forgings in smaller engines. Industrial equipment industries use forgings in materials handling systems, conveyors, chain-hoist assemblies, and lift trucks. "Forged" is the mark of quality in hand tools and hardware. Pliers, hammers, sledges, wrenches, and garden implements as well as wire-rope clips and sockets, hooks, turnbuckles,and eye bolts are common examples. Strength, resistance to impact and fatigue, and excellent appearance are reasons why forgings have been the standard of quality since the earliest of times. The same is true of surgical instruments. Special hardware for electrical transmission and distribution lines is subject to high stresses and corrosion. For strength and dependability, forgings are used for parts such as pedestal caps, suspension clamps, sockets, and brackets.

5 Identified Barriers and Needs

The Forging Industry Technology Roadmap has identified those projects most likely to increase the global competitiveness of the North American Forging Industry. This section outlines the requisite programs needed to achieve the industry's objectives.

Die Materials

Die cost reduction and die life extension are critical to increasing the global competitive stance of the forging industry.

- Tool material cost increases (impact of Global Sources)
- Develop more restrictive specifications for forge quality tool steel
- Database to characterize various grades (machinability/tool life/wear/toughness)
- Standard to capture "total tool life"
- Standardized tool material grades (including manufacturing process)
- Heat treat
    - -Testing
- Non-iron based material
    - -WC (Tungsten Carbide) for warm/hot forging
    - -Ceramics
    - -Metal matrix composites
    - -Nickel-Base Alloys (machinability)
- Knowledge base for die material selection
- Manufacturability of chosen die materials
- Advanced die design tools and methodology

Die Surface Modification

Advanced techniques for die surface modification are necessary to increase die life and promote cost effective net shape forging.

- Numerical characterization of various parameters needed to enhance die life
- Self lubricating coating
- Laser modifications at the micro level
    - -Surface texturing to retain lubrication
- Welding/cladding/overlays
- Duplex coatings
- Surface engineering to utilize
    - -Welding & lubrication
    - -EDM
    - -Plating

Lubrication

Proper lubrication of the die cavity extends die life and ensures proper filling of the die.

- Application system that significantly reduces lubrication usage
  - -Accurately
  - -Selectivity
- Alternate to graphite
- System to measure lubrication effectiveness
- Tool surface texturing
- Lubricant that does not burn off
- Advanced billet coatings
- Solid lubricant

Simulation

Simulation software reduces the number of costly tryouts. The program can analyze a forging related problem and suggest possible solutions. Advancing existing simulation software is necessary to continued health of the forging industry.

- Software standardization
- Initial & on-going cost
- Training
- Effective 3D capability
- Material databases
- Forging preform design & analysis (reverse engineering)
- Integration of thermal mechanical processing (TMP) plus heat treat (H.T.) with finite element modeliing (FEM)
- Simulation & prediction of failure modes
- Friction & Heat transfer models
- Advanced 3D simulation programs
  - -Cost
  - -Training/personnel
- Simulation of all systems in a forging plant

6 Priority Research and Development

The priority research and development areas and goals to overcome major barriers to improving the forging industry are listed below. R&D needs exist in specific areas of forging process: die materials, die surface modification, lubrication and simulation. The R&D goals are categorized as high, intermediate and long-term priority.

The goals are aligned by time frame when useful results can be expected.

Identified Project Priorities

Group A – Die Materials, Die Surface Modification & Lubrication

Group A identified fourteen project priorities for consideration.

HIGH PRIORITY

Group Ranking 1 – Training/Improved Procedures for Selection & Use for Die Designers

FIERF/FIA Training for Selection & Heat Treatment of Tool Steels for Die Designers

FIERF/FIA should develop a detailed (3 day) training course for selection and heat treatment of tool steels for die designers. This course should also include basic training for identifying failure mode.

Scientific Tool Life Optimization Training (Six Sigma)

Develop a training course to educate industry engineers to use reiterative analysis of tool failures using advanced microscopy, metallurgy, simulation and statistics.

Billet Induction Heating Temperature Specifications for Extended Die Life

Customers provide a wide range of temperature bands, tolerances and specifications that can effect system costs. Need a standard that is understood by forgers. Need to evaluate application processes for material for best forging results based upon temperature profiles.

Group Ranking 2 **-** Improved Lubrication

Alternate to Graphite Lube

Develop additional environmentally friendly and effective alternatives to graphite lube for warm and hot forging.

INTERMEDIATE PRIORITY

Group Ranking 3 – Improved Lubrication

Lubrication Application

Develop proper lubrication application standards.

Robotic Spray Application of Forging Die Lubricant

Separate the cooling and lubricating functions so as to reduce overspray and emissions. Improve the environment. Make forging industry aware of improved application techniques.

Group Ranking 4– Die Life Improvement

Surface Engineering System for Increased Die Life

A customized optimized die coating for minimum die related cost. Engineering approaches and guidelines for use of engineered surface.

Multi-Attribute Die for High Performance Forging

An engineered die for gradient segment (wear, notch strength/cracking).

Manufacturability of Chosen Die Material

As a die material serves the forge process better, it often becomes less "machinable", therefore, EDM. How far can we improve tool life when "machinability" is not the primary concern; composite dies; develop knowledge base for material applications and how it is used (prepared, machined, used).

Improved Die Life Through Surface Enhancements of Die Materials

Formulate surface treatments that are machinable and have improved wear resistance without breakage. (Five times present die life.)

Optimized Die Fabrication Through Welding/Cladding/Overlays

Decrease die steel costs by utilizing "ideal" base material combined with varying types of welded or clad alloys. (This is one phase of the multi-attribute die.)

LONG TERM PRIORITY

Group Ranking 5 – Die Surface Engineering

An Automated Die Surface Engineering & Repair System for Dies

System that is able to recognize wear and failure in dies and is able to repair the failed areas using the original CAD of the die.

Group Ranking 6 – Die Materials Database

Numerical Characterization of Die Material/Modification Surface Properties of Wear Resistence/Fiction

Develop standard tests for wear resistance/friction; Evaluate each die material with the standard test (wear); Evaluate each surface coating with the standard test (friction).

Group Ranking 7 – Develop Die Coatings

Silicon-Nitride Coated Dies for Forging Aluminum Alloys

SiN is chemically inert to aluminum. This should simplify lubrication for aluminum forging, possibly eliminate need.

Group B – Simulation, Database Development and Closed Loop Control

Group B identified twenty seven project priorities for consideration.

HIGH PRIORITY

Forging Data Acquisition/Flow Stress Database Development

Prioritize materials & test methods; Select alloy types, parameters, temperature, strain rate; develop initial data; test; validate against actual process; make available for restricted distribution.

Automated Preform Design

Develop a computer program to automatically optimize the design of the preform.

Development of Radiant Heating Heat Treat Furnace Technology & Process Control

Major reductions in energy & solution time for parts in a furnace. Maintain fine grain size in heat treating.

INTERMEDIATE PRIORITY

Final Forging Distortion

Integrated modeling system. Model forging (3D); trim and cooling (3D with residual stress); heat treat (3D with residual stress and distortion); machining (3D with residual stress and distortion).

Failure Criteria for Forgings and Forging Alloys

Development of realistic/verifiable failure criteria for forgings to be used within simulation software.

Develop Models for Die Failure (Wear, Fracture, etc.) in Forging

To build database of relative failure resistance of die materials used in forging to aid in design decision-making.

Fatigue Performance Evaluation & Prediction of Forged Components Resulting from Forging Process Parameters

Evaluate, in a quantitative manner, forging process parameters effects on end performance in service.

Press Process Feedback Loop Control

Make available to the forging industry all the process controls that are presently available. Instrument press with variable frequency drive and feedback sensors to improve part-to-part consistency, press strain load and predictive maintenance.

Develop sensors to pinpoint press failure modes.

Required Heat Up Times for Large Forgings

Determination of minimum required soak times for large forgings challenging the historical non-scientific hold times currently used.

Simulation of Part Distortion in Heat Treatment

Determine which materials/shapes will/will not distort and by what amount.

Development of Harsh Environmentally Tolerant Sensors to Measure 3D Stresses at Any Point on a Machine Component, Die, or Mechanical Device

Stresses internal to machining parts, press structures and dies are usually undefined during operation. This work would create a system for definition.

Energy Conservation/Real-Time Energy Cost/Part Monitor

Systems to monitor energy use and costs (hardware/software).

Simple 3D Simulation/Training

Provide lower cost/user friendly 3D software for smaller companies.

LONG TERM PRIORITY

Prioritization of Process Control Towards Forging Quality

Evaluate effects of process variables on part quality and effects of process uncertainty. Identify important process variables and control methodology.

Materials Rationalization Database – Steel

Thousands of grade variations exist when a limited number could be employed to reduce confusion and reduce cost.

Rapid Forging Manufacturing for Vintage (Legacy) Systems

Provide forgings to replace worn or broken components. Vintage systems may be military or commercial systems such as automotive or machine tools.

Impact of Simulation on Flexibility and Shop Floor Performance

Investigate the potential of simulation to increase responsiveness to customer needs, reduce lead-time, cut inventory and improve productiveness.

Implementation Tool Management System (Database)

Develop computer-based system to oganize and manage the industry's most valuable assets (tools).

Design Parameter for Expert Forging Simulation Software

Articulate what capabilities, database and expertise is needed in an expert simulation program. Will go from bar to heat treated part.

7 Attendees

Mr. Sailesh Babu
Ohio State University

Mr. Murali Bhupatiraju
Metaldyne

Mr. Tom Borton
Thomas Borton Associates

Mr. Douglas Brown
Inductoheat, Inc.

Mr. Michael Crews
Metaldyne

Mr. Tzyy-Shuh Chang
OG Technologies

Mr. George Currie
Erie Press Systems

Mr. Paul Dimitry
MacSteel

Mr. Nitin Doijad
SMS Eumuco Inc

Professor Ali Fatemi
University of Toledo

Professor John Frater
Cleveland State University

Mr. Jim Gaida
Ajax Tocco Magnethermic

Mr. Ernie Gibson
Metaldyne

Professor Jay Gunasekera
Ohio University

Mr. Darrell Hammock
Weld Mold Co.

Mr. Marty Hausermann
Hausermann Die & Machine

Mr. Dale Hutchinson
Acheson Colloids

Mr. Swee Leong
National Institute of Standards and Technology

Ms. Karen Lewis
Forging Industry Educational and Research Foundation

Mr. Len Liuzzi
L & L Associates

Mr. Dale McCartney
Erie Press Systems

Mr. Manish Mehta
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Professor Bhavin Mehta
Ohio University

Mr. William Michaud
Scot Forge

Mr. George Mochnal
Forging Industry Association

Mr. Kasi Nath
American Axle & Manufacturing

Mr. Bob Noel
Metal Forming Consultants

Mr. John Nowak
Walker Forge

Mr. Tom Oakwood
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Mr. Tom Oberg
Cooper Hand Tools

Mr. Ken Phillips
Firth Rixson Viking

Mr. Jim Pindel
The Oilgear Company

Mr. George Pirics
Metalist International

Mr. Al Sabroff
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