

## A Technical History of Powder Forging – Lessons Learned for Technology Transition

Howard A. Kuhn<sup>1,a</sup>

<sup>1</sup>The Ex One Company 8001 Pennsylvania Avenue Irwin PA 15642 USA

<sup>a</sup>howard.kuhn@exone.com

### Abstract

*Powder forging has progressed in three decades through the stages of incubation, growth, and maturity, now accounting for 8% of the \$5 B global PM market. In this presentation, a history of the technical development of powder forging will be recounted, from early failed attempts and misconceptions, through seminal academic and industrial research, to technical and commercial success. Discussion covers the contributions of government and industrial funding, fundamental knowledge development, and industrial champions for successful implementation. The focus is on lessons learned that may be beneficial to the transition of other technologies for the powder metallurgy industry.*

**Keywords:** powder forging, technology transfer

### 1. Introduction

The powder metallurgy industry's traditional strengths in production of high precision, net-shape parts had always seen limited applications because of the lack of high performance material properties. As a result, various methods were developed to reduce or eliminate porosity – the primary source of reduced strength and failure in powder parts. One approach to achieving high, nearly theoretical, density involves forging of a compacted powder preform, or powder forging (PF).

While several attempts were made to hot forge powder preforms as early as 1941, serious attention was directed to the process in the late 1960s. Gleason, Federal Mogul, Fiat, Delco Moraine, Burgess-Norton, Cincinnati, Inc. and many others conducted pilot and limited production programs for automotive drive train components such as bevel pinion and side gears, stator cams, bearing races, and torque converter clutch hubs. At one point PF was touted as the panacea for all powder metallurgy components having high performance requirements, but it soon became apparent that commercial success was reserved for parts containing large holes, such as connecting rods, ring gears, and clutch races.

In 1984, after successful application of powder forged connecting rods was demonstrated by GKN (Porsche 928) and Toyota (Celica), Ford adopted powder-forged connecting rods for its 1.9 L engine, which completed the transition of powder forging from emerging process to commercial viability. Today, PF applications include connecting rods for all Ford engines (recently, the 6.0 L PowerStroke diesel was added), Hyundai's Lambda engines, and numerous other engines, plus input ring gears and clutch races for various automotive transmissions.

Following is a description of the path toward success of powder forging, illustrating the technical challenges, research funding sources, fundamental knowledge development, and

early industrial champions. Lessons learned from this evolution to commercial success may provide useful guidelines for the transition of other emerging technologies.

### 2. Technology Development

Most of the early attempts at PF occurred within powder metallurgy arenas, unfamiliar with the nuances of cracking, lack of die fill, and die chilling that accompanied plastic deformation during hot forging of powder preforms. One misconception that abounded was that the preform first densified under compression and then underwent lateral flow to fill the die. In another case, an unnecessarily complicated forging system was devised based on the notion that a double acting press was required, as in conventional powder compaction.

As basic research into powder forging was initiated at several industry labs and universities,<sup>1,2</sup> a deeper understanding of the differences in deformation behavior between powder compaction and powder forging emerged. Also, powders specifically tailored for forging were formulated.<sup>3</sup>

One university research program of note was initiated in 1968 at Drexel University in Philadelphia, PA, USA. Under a program called Themis, funded by the US Department of Defense, a comprehensive study of all phases of powder metallurgy was undertaken, including powder forging. This and similar programs brought other disciplines, such as mechanical engineering and industrial engineering, to bear on the problem. One outcome was definition of the fundamental deformation and fracture behavior of sintered powder materials under the plastic flow conditions of forging. The important roles of shear deformation to enhance densification and improve dynamic properties of the material were clarified.<sup>4,5,6</sup>

An industrial consortium was formed in 1973 to translate

this fundamental information into rules of thumb and design guidelines for application to actual parts. A major key to successful process development was proper design of the powder preform so that the forging process produced a fully dense part without cracking. For this purpose, procedures were devised for modeling the deformation process. One approach involved cold forging of aluminum powder preforms at room temperature, using low-cost tooling, to simulate hot forging of steel powder preforms; another approach used plasticine in Plexiglas dies to visualize the flow of metal in complicated geometries. The latter was used to determine the proper preform details in the critical junctions between pin end and beam, and crank end and beam of the first Ford connecting rod.<sup>7</sup> Today, such simulations are performed by finite-element modeling.

Further insights came with the application of heat transfer principles to quantify the effects of chilling of the hot preform in contact with the die. Such results provided guidelines on proper clearances between the preform and the die, particularly in critically stressed regions where surface porosity might cause failure in the part during use. This same analytical approach was used to determine die dimensions and temperatures so that the forged preform would meet its design tolerances upon cooling to room temperature.<sup>7</sup>

### 3. Industrial Implementation

Finally, the best technology in the world will never see commercial light unless it has an industry champion who is dedicated to rallying management support and funding to conclusion. In the case of Ford's connecting rod, this persistent champion was Stan Mokarski. After initial efforts to forge connecting rods from powder preforms in 1971, the technology was shelved, apparently because of product liability concerns rampant in US industry at that time. Ford revived their program in 1980, applying fundamental knowledge that had been developed in the meantime to improve the efficiency of the process and reduce relative production costs, which accelerated its implementation.

In addition, the improved PF connecting rod incorporated the "cracked rod" concept whereby the crank end cap is removed from the rest of the rod by fracturing at low temperatures along a forged-in stress concentration notch. This eliminates a sawing operation, and the cap makes a perfect match with the rod along the brittle fracture surface, avoiding fretting fatigue in operation. Furthermore, balance pads were eliminated at the crank and pin ends because the weight distribution in powder preforms was much more uniform than in forged and cast rods.

The maturity of the powder forging industry is reflected in the fact that standards have been developed (MPIF 35-2000 and ASTM B848-01). The technology has also withstood a recent challenge by conventional steel producers to replace powder forging with C70 bar stock. Powder forging even became the center of an international scandal involving the transfer of trade secrets and process details.

### 4. Summary

Although the powder forging process has a very small niche (8%) in a relatively small segment (\$5 B global P/M market) of the metal parts producing industry, its history holds some keys to successful technology development and transition to commercial practice:

- i) Determine the real need and find the best applications; don't try to solve all problems with the new technology.
- ii) Develop the technical foundation of the materials and process in concert, using appropriate technical domain resources; put the results into a form that is useable in industrial practice.
- iii) Use prototyping at all levels, including bench experiments, analytical methods, and pre-production trials.
- iv) Find, or be, the industrial champion to guide implementation of the process through the cultural barriers and infrastructure of "early adopter" industrial enterprises.
- v) Don't short-change any of the above.

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