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# Connecting Rod Evaluation

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## Introduction

Since 1986, more than 500 million powder forged (P/F) connecting rods have been manufactured and installed in automobiles worldwide. The application of forging a preformed near-net shape consolidated from metal powder has been widely accepted since the early eighties and today is the preferred manufacturing technique for 60% of the connecting rods manufactured in North America. The remaining portion of the connecting rod market segment is produced by use of either conventional steel forging, or to a lesser extent, casting manufacturing processes.



While the two competing forging processes are similar, there are a number of subtle differences between the two. The forged steel rod is fabricated by starting with a wrought steel billet, heating the billet and forging it in the material's plastic temperature range, fracturing or cutting the rod cap end, and then machining portions of the product to realize the final dimensional characteristics of the component.

The powder forged (P/F) rod is: fabricated by consolidating metal powders into a preform that is sintered, reheated to forging temperature (or in some cases forged subsequently to sintering), fully densified by forging to final shape, fracturing of the rod cap end, and then machined (minimally) to final dimensions.

All connecting rods function in internal combustion engine environments and are subjected to high rate cyclic loading requiring exacting tolerances and fits to mating components, such as the crankshaft and piston head.

Until the advent of the crackable P/F connecting rod cap end, all connecting rod cap ends were sawn or machined apart to enable inclusion of a bearing and attachment to the crankshaft.

The cost of sawing and machining the cap end to meet tolerances in finish and fit were a considerable portion of the manufacturing cost and sawing required that the internal diameter of the rod cap end account for the “kerf” of the sawn area in the shape of the “hole” (it was formed slightly out-of-round). A “crackable” rod cap end provides the advantages of lower cost to separate the cap end, the surfaces of the cracked ends mate better and more accurately when reassembled after machining and the tolerances of the cap end internal diameter can be closely held to a perfectly circumferential circle. From the conventional method of splitting connecting rods with twenty steps, the fracture splitting method reduced the process to ten steps, all essentially machining, honing or drilling steps.

Connecting rod manufacture is a high volume, price sensitive application with strict performance, design and durability requirements. Process or material improvements leading to lower costs result in large scale cost savings. Annual North American production is approximately 100 million rods.

## **The C-70 Story**

A new steel, C-70, has been introduced from Europe as a crackable forging steel. Alloying elements in the material enable hardening of forged connecting rods when they undergo controlled cooling after forging. This material fractures in a fashion similar to powder forged materials.

Recently the American Iron and Steel Institute’s (AISI) Bar and Rod Market Development Group has promoted C-70 as an improved material over P/F alloys on the basis of optimization work and economic analysis performed by a candidate for a Master’s of Science Degree in Mechanical Engineering at the University of Toledo. The thesis advisor was Dr. Ali Fatemi.

The study investigated weight and cost reduction opportunities of steel forged connecting rods. Analysis focused on comparing and then optimizing a rod design using crackable forged steel (C-70). Using finite element analysis (FEA) techniques, the author was able to reduce the weight by 10% and by using “crackable” C-70, reduce the costs by 25% (over current forged steel connecting rods) and ostensibly 15% less than a P/F rod with similar or better fatigue behavior.

The study identified fatigue strength as the most significant design factor in the optimization process.

The AISI funded study focused on using FEA analysis to show where and how the original connecting rod design configuration could be reconfigured to reduce weight and by using the “crackable” C-70, to eliminate some cost considerations.

## **Powder Forging Process**

Powder forging consists of the rapid densification of a heated powder-based preform using a single forging strike. The result is a fully dense net- or near-net shape part suitable for high performance applications where high durability and strength are a requirement.

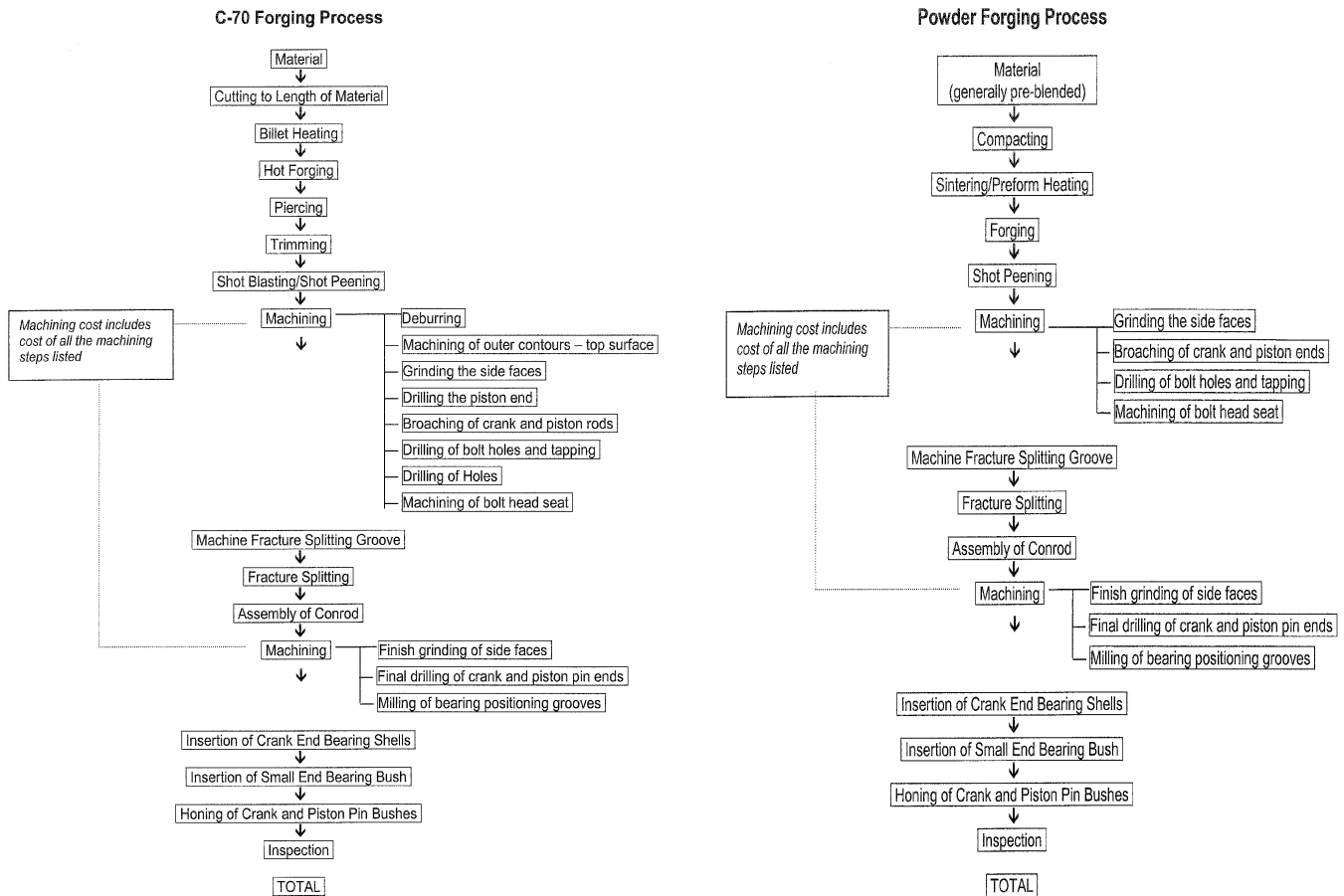


The initial step in the process is to cold compact metal powder to shape close to the final forge shape. This green compact is then heated/sintered in a controlled atmosphere furnace. In most automated production lines, the “sintered” preform is then rapidly transferred into a trap forging die where the material is then forged to full density and net shape.

Tight control of the powder preform mass allows the use of a trap die and eliminates any material waste such as the “flash” usually associated with the conventional forging process. Energy savings is another advantage of the process when the forging step directly follows the sintering step, eliminating re-heating. Powder forging is done at a lower forging temperature than conventional forging.

The use of near-net shape preforms results in less material flow resulting in longer tool life. Careful design of the preform also enables controlled material flow that can result in enhanced mechanical properties aided by the uniform fine grain of the material. Controlled cooling of the forged part impacts productivity and energy savings thus eliminating the necessity for cooling and reheating for heat treatment.

Below are flow charts comparing the steps of powder forged and conventional (C-70) forging processes:



## Material Comparisons

Most forging grade alloy powders use nickel and molybdenum and small amounts of manganese to enhance iron hardenability without developing stable oxide formation. Copper is also frequently admixed in the case of connecting rods.

Wrought steel bar stock undergoes extensive deformation during cogging and rolling of the original ingot. This creates inclusion stringers and thus places of weakness. The mechanical properties of these materials can vary considerably depending on direction of the piece's rolling and forming history. P/F materials undergo little material deformation resulting in isotropic mechanical properties, contributing to superior fatigue resistance. Mechanical properties are further enhanced by better surface finish and finer grain size.

There are several schools of thought on material selection of powder forged connecting rods. One school suggests that P/F rod material should use an additive such as manganese sulfide to increase rod machinability, as a route to cost control. The other school of thought suggests that alloying should aim for better properties as a route to an optimized design and lower cost, thus balancing the performance-cost equation. In the latter case, copper is the alloying agent and recently the two compositions shown below in Table I were used in side-by-side testing with C70.<sup>(1)</sup> Fatigue strength is very dependent upon design factors, so sets of rods were made from HS150™, HS160™, and C-70. The rods used for these tests had the same shape in the “I-Beam”.

**Table I: Chemical Composition of Powder Forged Materials**

|               | <b>Cu</b> | <b>C</b> | <b>Mn</b> | <b>S</b> | <b>Fe</b> |
|---------------|-----------|----------|-----------|----------|-----------|
| <b>HS150™</b> | 3.06      | 0.50     | 0.31      | 0.12     | Bal.      |
| <b>HS160™</b> | 3.03      | 0.57     | 0.33      | 0.12     | Bal.      |

Axial constant amplitude, fully reversed (stress ratio  $r = -1$ ) and offset loading (stress ratio  $r = -2$ ) fatigue tests were conducted. Twenty piece staircase tests were completed and the results are shown in Figure 1.

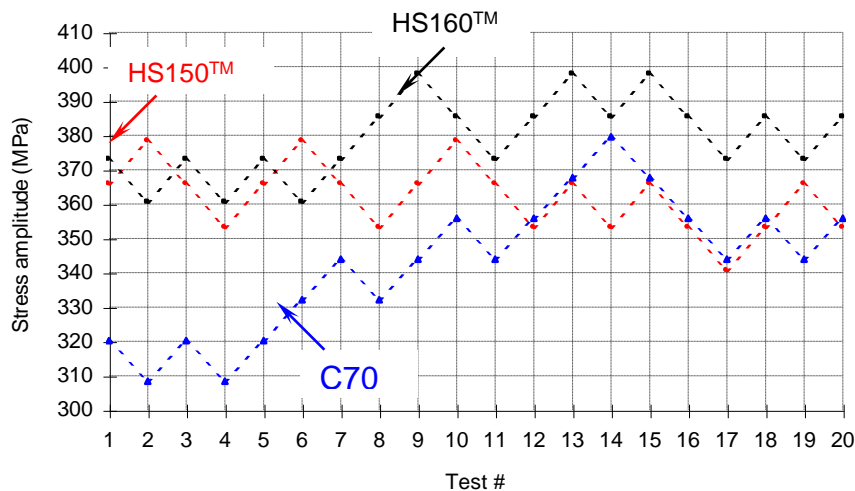


Figure 1: Summary of the staircase test results,  $r = -2$ , HS150™, HS160™, and C-70.

The summary of the fatigue limits @ 90% probability of survival at  $r = -2$  is shown in Table II. Notice that the C-70 scatter is four to six times higher than the P/F rods.

**Table II: Fatigue Test Results (Connecting Rods,  $r = -2$ )**

|                                  | <b>HS160™</b> | <b>HS150™</b> | <b>C-70</b> |
|----------------------------------|---------------|---------------|-------------|
| <b>Fatigue Limit @ 90% (MPa)</b> | 363           | 352           | 283         |
| <b>Scatter (MPa)</b>             | 8             | 13            | 48          |

Similar results are found in Table III at a stress ration of  $r = -1$ .

**Table III: Fatigue Test Results (Connecting Rods,  $r = -1$ )**

|                                  | HS160™ | HS160™ | C-70 |
|----------------------------------|--------|--------|------|
| <b>Fatigue Limit @ 90% (MPa)</b> | 335    | 328    | 252  |
| <b>Scatter</b>                   | 10     | 13     | 58   |

## Summary

The implication of the above data is that P/F materials demonstrate improved fatigue strength on the order of 25–33% over C-70 material of the same design. As a result of the lower scatter a more robust and compact product may be obtained through powder forging

The AISI study did not indicate, evaluate or deploy the FEA analysis technique to show what could be done to optimize the P/F rod under similar constraints. If indeed one performed an analysis using P/F materials and recognized the 25–33% better fatigue properties of P/F alloys in direct comparison with C-70, it seems that P/F materials could realize significant weight reductions. The process cost analysis seemed to ignore that P/F rods have always been split by fracture splitting and hence that is another indication that there is some doubt as to the accuracy of the AISI Study's conclusions.

Thus, by changing the design criteria, it could be inferred that cost savings could be realized when using P/F materials without sacrificing product performance.

*Photos: Courtesy of GKN Sinter Metals*

- (1) Iliia, Edmond, Tutton, Kevin and O'Neill, Mike, "*Impact of Copper and Carbon on Mechanical Properties of Iron-Carbon-Copper Alloys for Powder Metal Forging Applications*", *Advances in Powder Metallurgy & Particulate Materials*, Vol. 3, compiled by R.A. Chernenkoff and W.B. James, Metal Powder Industries Federation, Princeton, NJ, 2004, part 10, pp. 98–110.