ONE IN A SERIES

WHITE PAPER #21

Powder metallurgy materials can attain fatigue integrity equal or superior to that of cast/wrought counterpart materials.

Studies have shown that material fatigue annually contributes to an estimated $600 billion in losses.[1] Starting in the early 1800s, concepts have evolved into today's models and tests to prevent fatigue failure in products and components. Fatigue is generally caused by repeated loading and unloading forces on a material or product until microscopic cracks are formed. Ultimately these microscopic cracks reach a critical size and the structure fails. Today there are three approaches to analyzing and designing against fatigue: 1) stress-based approach; 2) strain-based approach; and 3) the fracture mechanics approach. To examine fatigue, one needs to evaluate the load cycle, component geometry, and material properties.[2]

Powder metallurgy (PM) materials by nature are porous and thus the amount, shape, size, and location of the pores are critical to the structure's fatigue resistance. The key issue here is the porosity or its inverse, density. Pores act as stress concentration sites for fatigue crack initiation, so the control and location of these sites is critical to fatigue life of the structure. PM fabricators have learned to engineer their materials and use various treatments including heat treatment, double pressing and double sintering, sizing, and case hardening to control pore shape, pore size, and volume of pores to extend fatigue life. Also, surface porosity can be minimized by surface rolling and shot peening to densify the surface. While porosity is a dominant factor, component design, microstructure, material contaminants, and processing defects are also involved.[3]

For example, sintering temperature and cooling rates of PM steels can impact the static and fatigue strength of similar materials by modifying the pearlite spacing of the microstructure, thus affecting the pore shape as well as minimizing the number of pores. In addition to changing these factors, alloy additions, such as copper can increase the ultimate tensile strength by >30%.[4]

Microstructural characteristics determine fatigue performance. Sintering cycles can be chosen to refine the microstructure and enhance the sinter necks between the powder particles to improve performance. The difference can move the fatigue strength as shown in an evaluation of FL-5305 that, by changing the microstructure from upper bainite and conventional sintering to martensite and high-temperature sintering, the fatigue strength could improve from 275 MPa to 430 MPA.[5]

One of the principal methods to achieve full density in a PM material is to "forge" the compacted PM material blank to produce near-zero porosity. A recent comparison of two powder-forged (PF) materials and a traditionally processed and forged material C-70[6] shows the following results:

Table I: Chemical Composition of Powder-Forged Materials

	Cu	C	Mn	S	Fe	Si
HS150TM	3.06	0.50	0.31	0.12	Bal.	-
HS160TM	3.03	0.57	0.33	0.12	Bal.	-
C-70	-	0.70	0.25	-	Bal.	0.20

The summary of the fatigue limits at 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 PF rods.

Table II: Fatigue Test Results (Connecting Rods, r = –2)

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

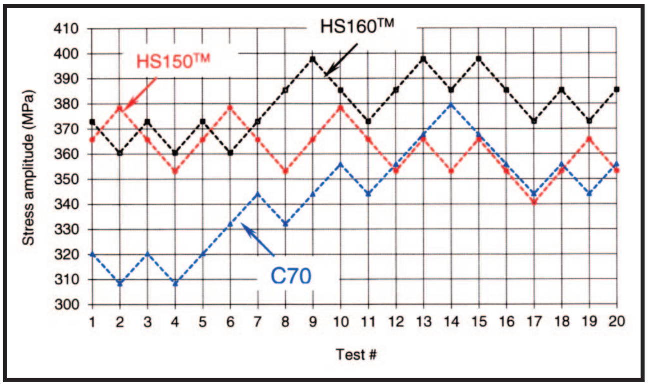

Figure 1. *Summary of the staircase test results, r = -2, HS150™, HS160™, and C-70*

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

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

	HS150™	HS160™	C-70
Fatigue Limit @90% (MPa)	335	280	252
Scatter (MPa)	10	13	58

The implication of the above data is that the powder forged (PF) HS materials demonstrate improved fatigue strength on the order of 25%–33% over C-70 material of the same design. The use of finite element analyses (FEA) could be considered to show what could be done to optimize the PF rod under the same constraints used to accept the C-70 rod. Thus, by changing the design criteria, it could be inferred that cost savings could be realized when using PF materials without sacrificing product performance.[6]

References

1. R.T. Warzel and S.H. Luk, “Effect of Processing Conditions on the Fatigue Response of PM Chromium Steels”, *Inter. J. Powder. Metall.,* 2012, vol. 45, no. 5, p. 18.
2. Ibid., p. 16.
3. Ibid., p. 17.
4. T.F. Murphy, B.A. Lindsley and C.T. Schade, “Effect of Pearlite Spacing and Chemical Composition on the Axial-Fatigue Behavior of Fully Pearlitic PM Steels: A Metallographic Study”, *Inter. J. Powder. Metall.,* 2012, vol. 45, no. 5, p. 25.
5. R.T. Warzel and S.H. Luk, “Effect of Processing Conditions on the Fatigue Response of PM Chromium Steels,” *Inter. J. Powder. Metall.,* 2012, vol. 45, no. 5, p. 22.
6. J.R. Dale. “Connecting Rod Evaluation”, white paper published by MPIF, 2005; www.pickpm.com/DesignCenter/ConRod.pdf