

Advancements in Powder Forged Connecting Rod Technology to Facilitate Downsizing of Direct Injection Turbocharged Engines

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ABSTRACT

The advent of more efficient direct injection turbocharged engines has increased the need for higher performance connecting rods, able to withstand in particular higher compressive loads in operation. In this respect, new high strength materials for powder forged connecting rods were developed and introduced in production with excellent results. Among them, HS170M is currently used to manufacture connecting rods for several high performance engines, which not only have higher strength, but have less variation in their mechanical properties. The results of numerous benchmark studies have shown that powder forged connecting rods manufactured with HS170M are stronger than their steel forged counterparts manufactured with microalloyed steels, are easier to machine and fracture split, and represent a cost effective way to manufacture this important high reliability automotive component. In addition, advancements in design and manufacturing of powder forged connecting rods, such as design optimization, post-delubrication shot peening, enhanced shot peening, forged-in-notch to facilitate the fracture split process, pin coating to eliminate the use of bushings, etc., make powder forged connecting rods a very attractive option to the automotive industry. These improvements have resulted in higher performance of powder forged connecting rods in engines and, as a result, in mass reductions, thus further contributing to fuel economy and reduced emissions.

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HIGH STRENGTH MATERIALS FOR POWDER FORGED CONNECTING RODS

Copper and graphite are additives known to cost-effectively improve strength and hardness of automotive components manufactured through powder metallurgy, thus making Fe-Cu-C alloys the most widely used material. This statement applies to the dot to powder forged connecting rods, in which case almost 100% of them are manufactured with Fe-Cu-C alloys with different chemical compositions. Carbon, as an interstitial diffusing element, rapidly dissolves in iron during sintering, thus strengthening and hardening ferrite. Copper, which is instrumental during sintering due to its low melting temperature, is known to strengthen iron through substitutional solid solution. On the other hand, copper is effective in producing a finer grain structure during recrystallization that takes place after forging. In addition, as a result of copper additions, the eutectoid composition is shifted towards lower carbon levels, thus further increasing the amount of pearlite in microstructure and, ultimately, the strength. Lastly, known for its relatively high solubility in iron at high temperatures and for a continuously decreasing solubility at lower temperatures, copper can provide further strengthening through the second phase precipitation mechanism.

The chemical composition of Fe-Cu-C alloys has been optimized to achieve maximum performance and, as a result, high strength materials, such as HS150, HS160, and HS170 (the letter H stands for high, the letter S stands for strength, while the three digits represent

the approximate ultimate tensile strength of the material in 10³ psi, rounded up or down to the nearest decade) have been developed. It was shown that significant improvements in static and dynamic properties were obtained by simply increasing the copper content from 2% to 3% [1, 2]. In a second approach, it was proven through the development of HS150M, HS160M, and HS170M (the letter M stands for modified) that when the copper content is further increased from 3% to 3.25%, not only the strength improves, but its variation, as a result of chemical composition variation within the specified limits, is reduced [3, 4]. The chemical composition of HS materials currently used in mass production is shown in [Table 1](#).

Table 1. Chemical composition of HS materials (w/o).

	Cu*	C**	MnS*	Fe
HS150	3.00	0.48	0.32	Bal.
HS160	3.00	0.58	0.34	Bal.
HS170M	3.25	0.64	0.32	Bal.

*) added in the mix

**) measured in the as-forged product

After the introduction in production of HS150, which has superior mechanical properties to C70, several grades of microalloyed steels with higher strength were developed by the wrought steel forging industry. The tensile properties at room temperature (RT) of HS

materials and microalloyed steels [5] are summarized in Table 2. As shown, HS170M, the strongest material used by the powder forging industry to manufacture connecting rods, and 70MnVS4high and 46MnVS6mod, the strongest materials offered by the wrought steel forging industry to manufacture connecting rods have quite similar mechanical properties. 36MnVS4 has a very good yield strength (YS) as well but a relatively low ultimate tensile strength (UTS) while 70MnVS4, although has the same UTS as 36MnVS4, underperforms in YS. It is interesting to point out that the elongation of HS170M is very similar to the elongation of microalloyed steels, while the area reduction (AR) is higher in the case of microalloyed steels.

Table 2. Tensile properties at room temperature.

	UTS (MPa)	YS (MPa)	Elongation (%)	Area Reduction (%)
HS150	1039	730	15.2	22.8
HS160	1080	739	13.1	17.8
HS170M	1202	855	11.5	18.3
36MnVS4	1077	851	10.3	43.1
70MnVS4	1077	701	9.1	33.7
46MnVS6mod	1157	849	10.0	32.2
70MnVS4high	1217	823	9.0	19.2

The introduction of direct injection turbocharged and diesel engines has increased the need for components able to withstand higher compressive loads in operation. For this reason, the compressive yield strength (CYS) becomes a very important property to consider in the design phase of connecting rods. CYS test results on three materials are summarized in Table 3.

Table 3. Compressive yield strength at room temperature.

(MPa)	HS170M	C70	36MnVS4
CYS	840	571	818

As shown in the table, the CYS of HS170M is quite similar to the CYS of 36MnVS4 (the difference is approximately 2.7%).

PERFORMANCE BENCHMARK STUDIES

Although the static mechanical properties obtained from specimens machined from connecting rods show virtually no difference among HS170M and some of the microalloyed steels, the fatigue performance of connecting rods manufactured through the wrought steel forging technology usually underperforms the fatigue performance of powder forged connecting rods. Due to a higher variation in fatigue strength in the case of connecting rods manufactured through wrought steel forging, in many cases as a result of the effect of the trim line, which represents a stress riser, the fatigue strength at 90% survival rate (FS at 90% SR) is usually much lower [6]. A detailed analysis of defects encountered in wrought steel forged connecting rods can be found in [7], where the authors examined numerous polished surfaces of several sections cut from the I-beams of wrought carbon steel connecting rods. Their

examination revealed “a huge amount of internal defects such as folds, cavities, micro cracks, or small oxide flaws,” inherent to the wrought steel forging technology.

In order to evaluate the fatigue performance of connecting rods, the staircase method, in accordance with MPIF Standard 56 [8] was employed. The fixture set-up illustrated in Figure 1 was used throughout testing. Both crank and pin bores were machined in order to meet strict requirements for perpendicularity and parallelism, thus avoiding the induction of bending stresses. Cylindrical pins were press-fit into the bores and axial loads in tension-compression were applied at room temperature on a MTS servohydraulic closed loop controlled testing machine.

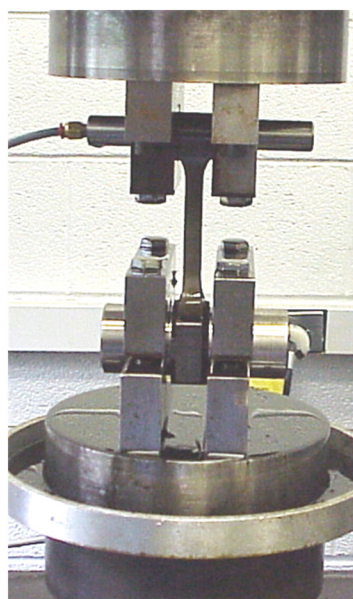


Figure 1. Fatigue testing fixture set-up.

Fatigue tests were conducted by the authors at different stress ratios on more than 200 commercially produced connecting rods manufactured through wrought steel forging with C70, 36MnVS4, 46MnVS6, and 70MnVS4, and purchased from dealerships across the globe as well as on mass production powder forged connecting rods. The test result was considered runout at 10,000,000 cycles (with exception of a couple of cases, when tests were suspended after 5,000,000 cycles).

The fatigue strength at 50% and 90% survival rate as well as the approximate standard deviation calculated in accordance with the staircase method [8] are summarized in Table 4 in the case of wrought steel forged connecting rods.

As shown in the table, the standard deviation, an indicator of variation in the performance of the components during fatigue testing, varies from a low of 5 MPa to an extremely high value of 74 MPa. As described in [6, 7, 9], this inconsistency in performance is related to the presence of several defects in the I-beam, in particular along the trim line.