



New Higher Strength Materials for Powder Forged Connecting Rods

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Content

- **Development of Higher Strength Materials for Powder Forged Connecting Rods**
- **Comparing Powder Forging with Drop Forging**
- **Mass Reductions Offered by Powder Forged Connecting Rods**
- **Conclusion**

Materials Development

The most widely used material to manufacture powder forged connecting rods consists in a Fe–Cu–C alloy (2% Cu, approximately 0.50% C, and 0.32% MnS to enhance machinability).

Goal: Optimize the chemical composition of Fe–Cu–C alloys for maximum strength

Materials Considered

Increasing the Cu content from the actual 2% to 3% or even higher would improve the strength for the following reasons:

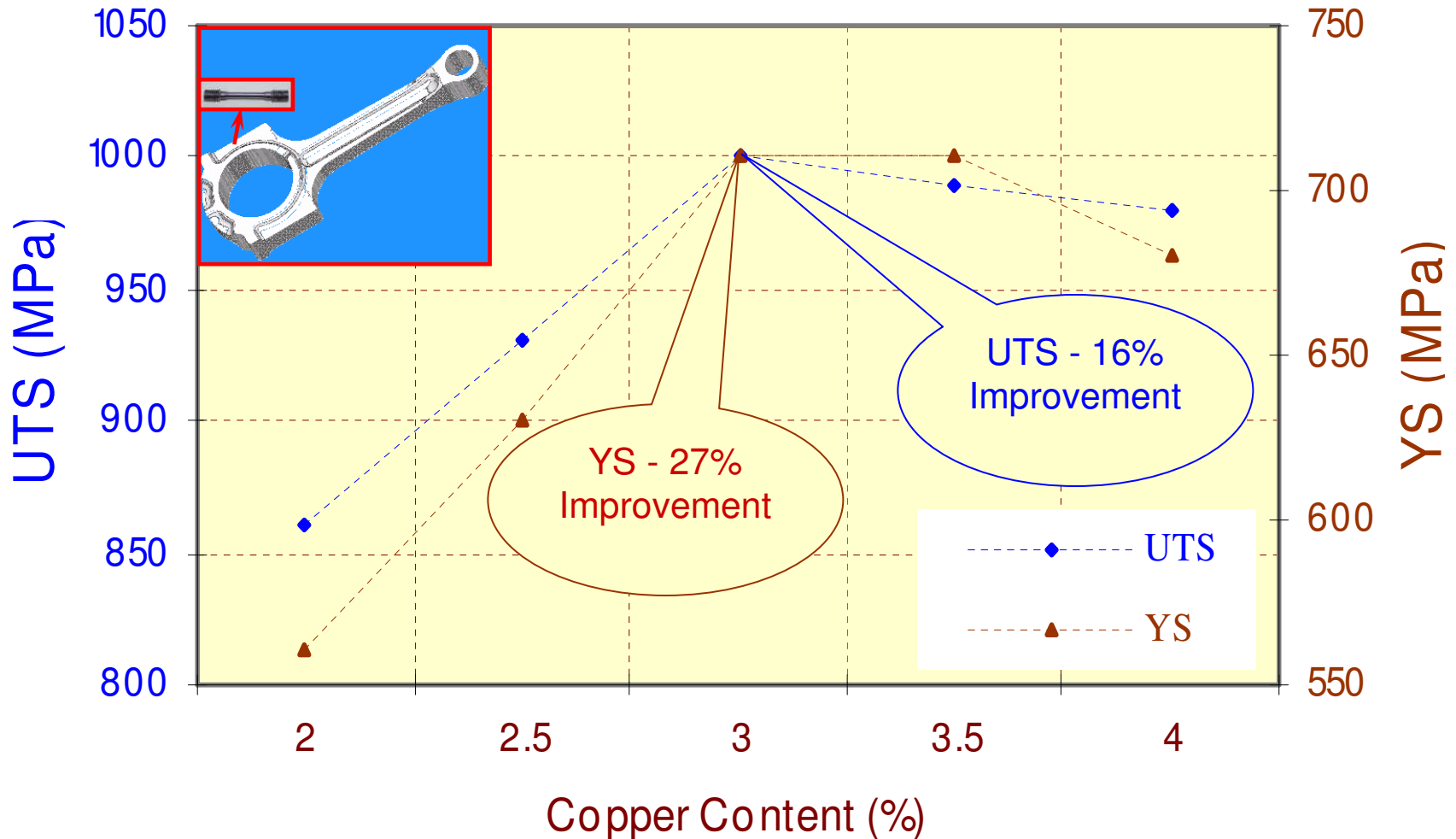
- Cu strengthens and hardens the ferrite
- Cu hinders grain growth after forging

Increasing the C content would further contribute to improving the strength, thus resulting in mass savings to the automotive industry

4.00	4Cu5C			
3.50	3.5Cu5C	3.5Cu6C		
3.00	3Cu5C	3Cu6C	3Cu7C	3Cu8C
2.50	2.5Cu5C			
2.00	2Cu5C	2Cu6C		
Cu/C	0.50	0.57	0.64	0.70

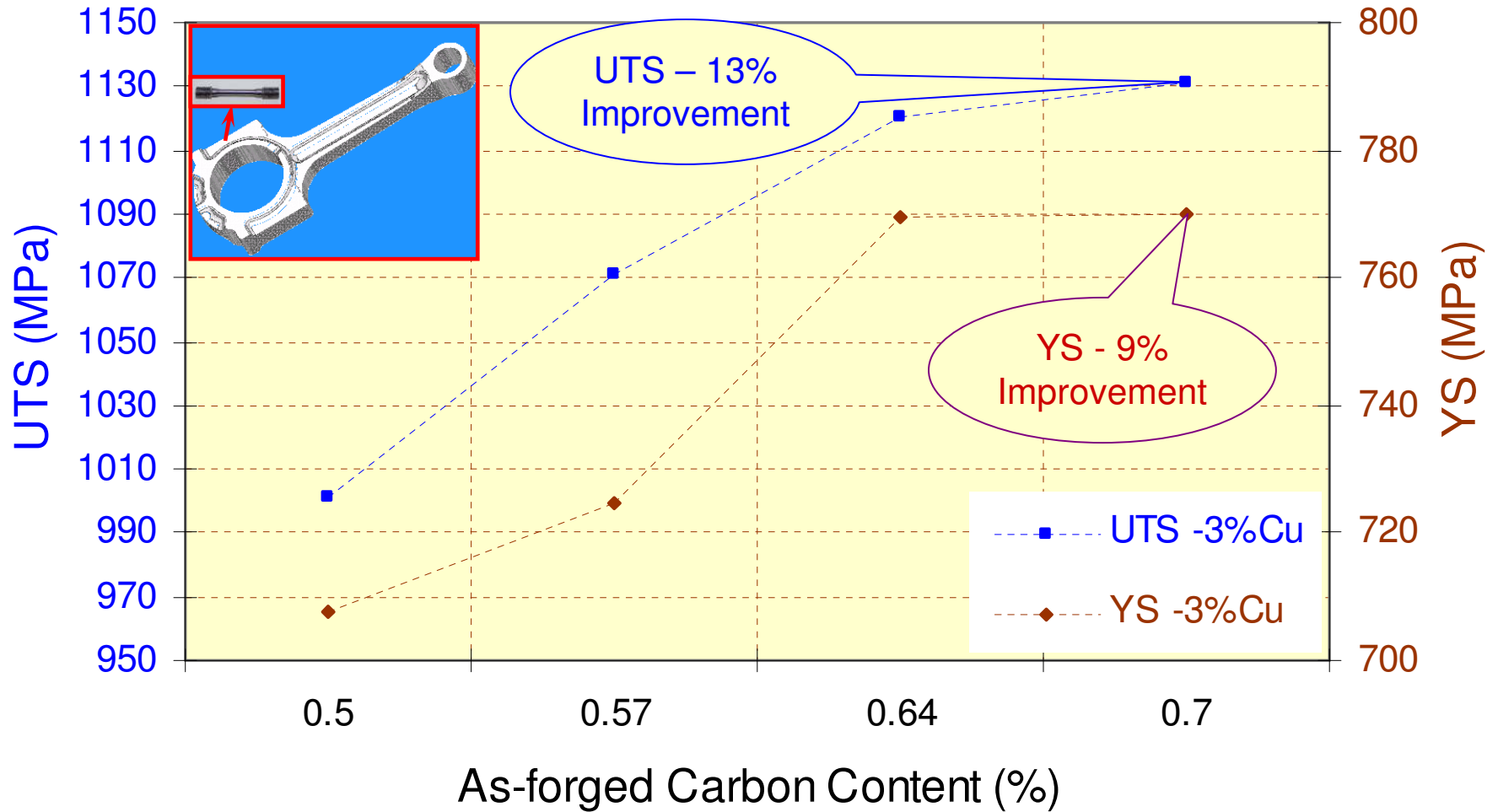
Tensile Test Results

Specimens – 0.50% as-forged C



Tensile Test Results

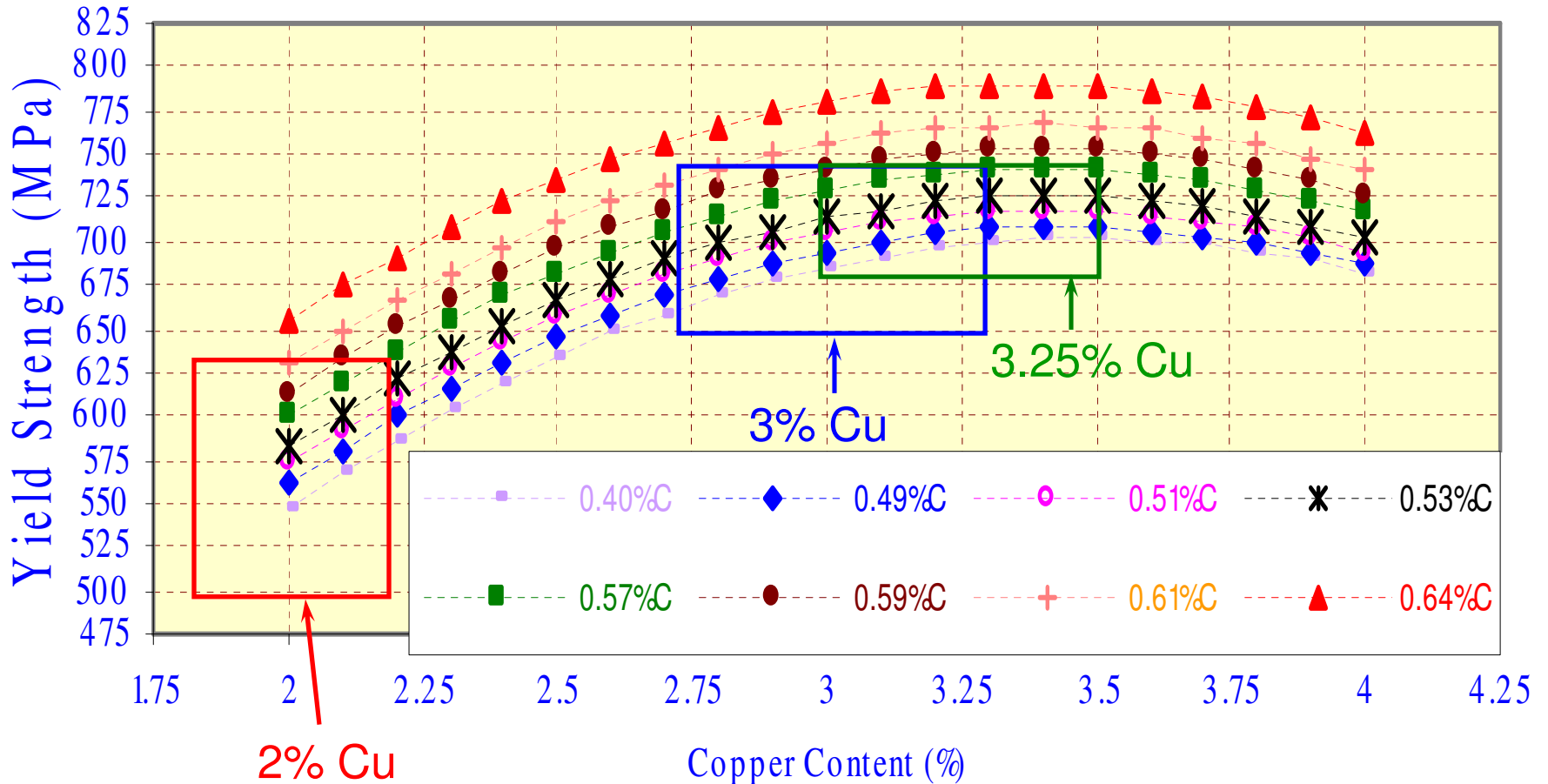
Specimens – 3% Copper



Optimization of the Chemical Composition

Tensile Testing - Specimens

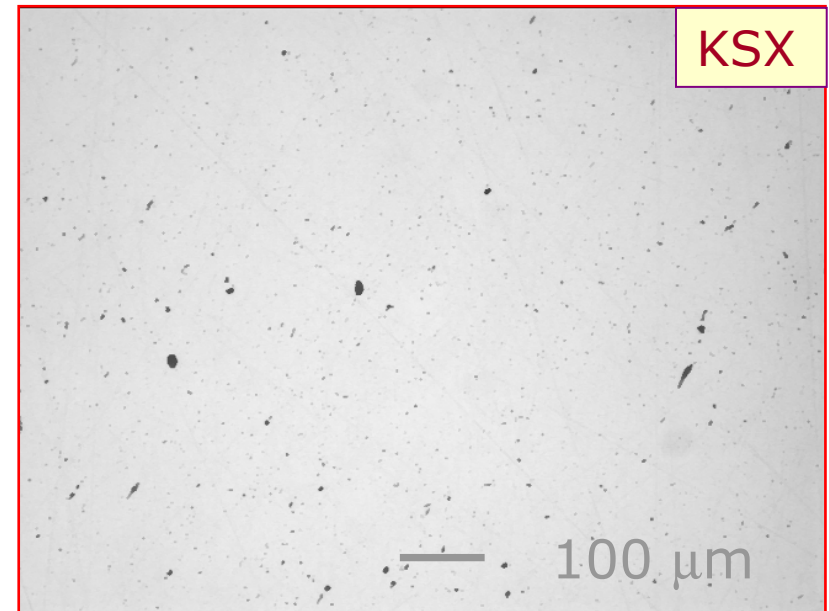
Cu 2 – 4%, step 0.5%, C 0.50 – 0.64%, step 0.07%



Materials Development

New Machinability Enhancer

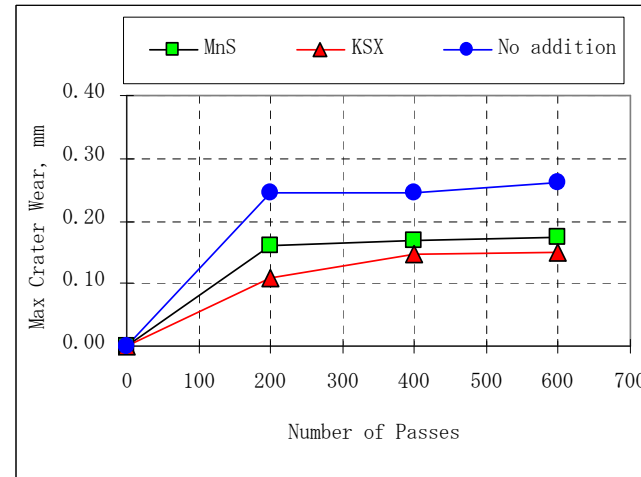
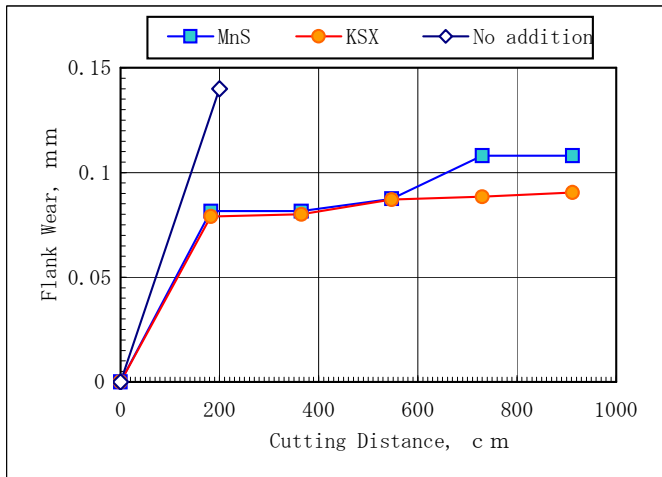
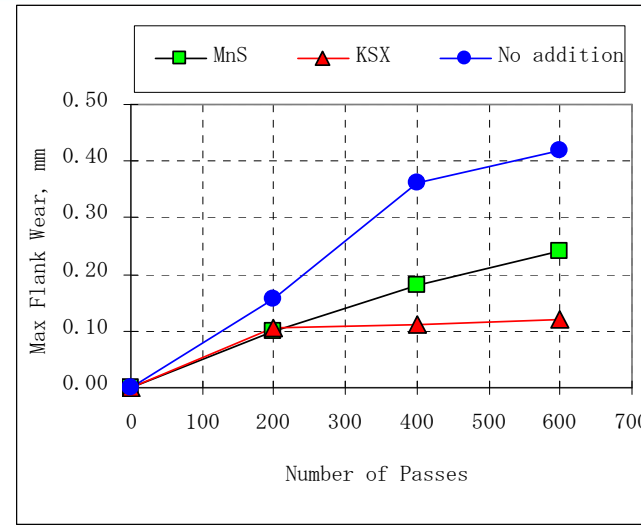
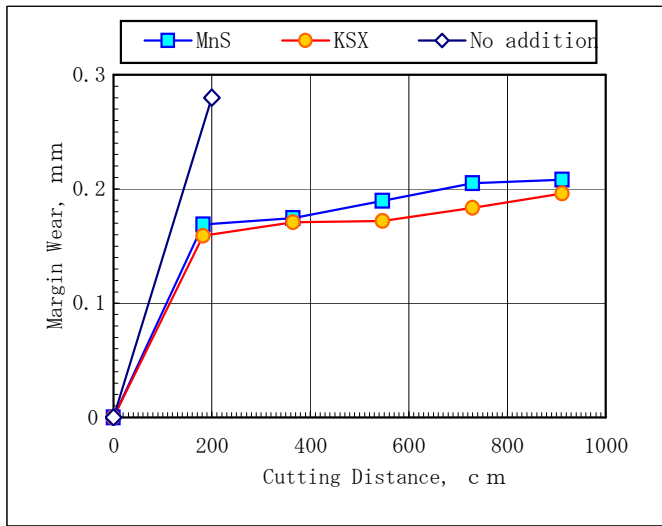
Unetched Microstructures



KSX particles are much smaller and rounder than MnS particles. This fact, coupled with lower amount (only 0.10% KSX is needed to replace 0.32% MnS), results in a less pronounced negative effect on fatigue strength, in particular in the case of PF products.

Materials Development

New Machinability Enhancer – 0.10% KSX vs. 0.30% MnS



DRILLING

BORING

Materials Development

	Cu	C	MnS	KSX
HS150	3.00	0.50	0.32	N/A
HS150M	3.25	0.50	0.32	N/A
HS150M+KSX	3.25	0.50	N/A	0.10

	Cu	C	MnS	KSX
HS160	3.00	0.57	0.32	N/A
HS160M	3.25	0.57	0.32	N/A
HS160M+KSX	3.25	0.57	N/A	0.10

	Cu	C	MnS	KSX
HS170	3.00	0.64	0.32	N/A
HS170M	3.25	0.64	0.32	N/A
HS170M+KSX	3.25	0.64	N/A	0.10

Fatigue Testing

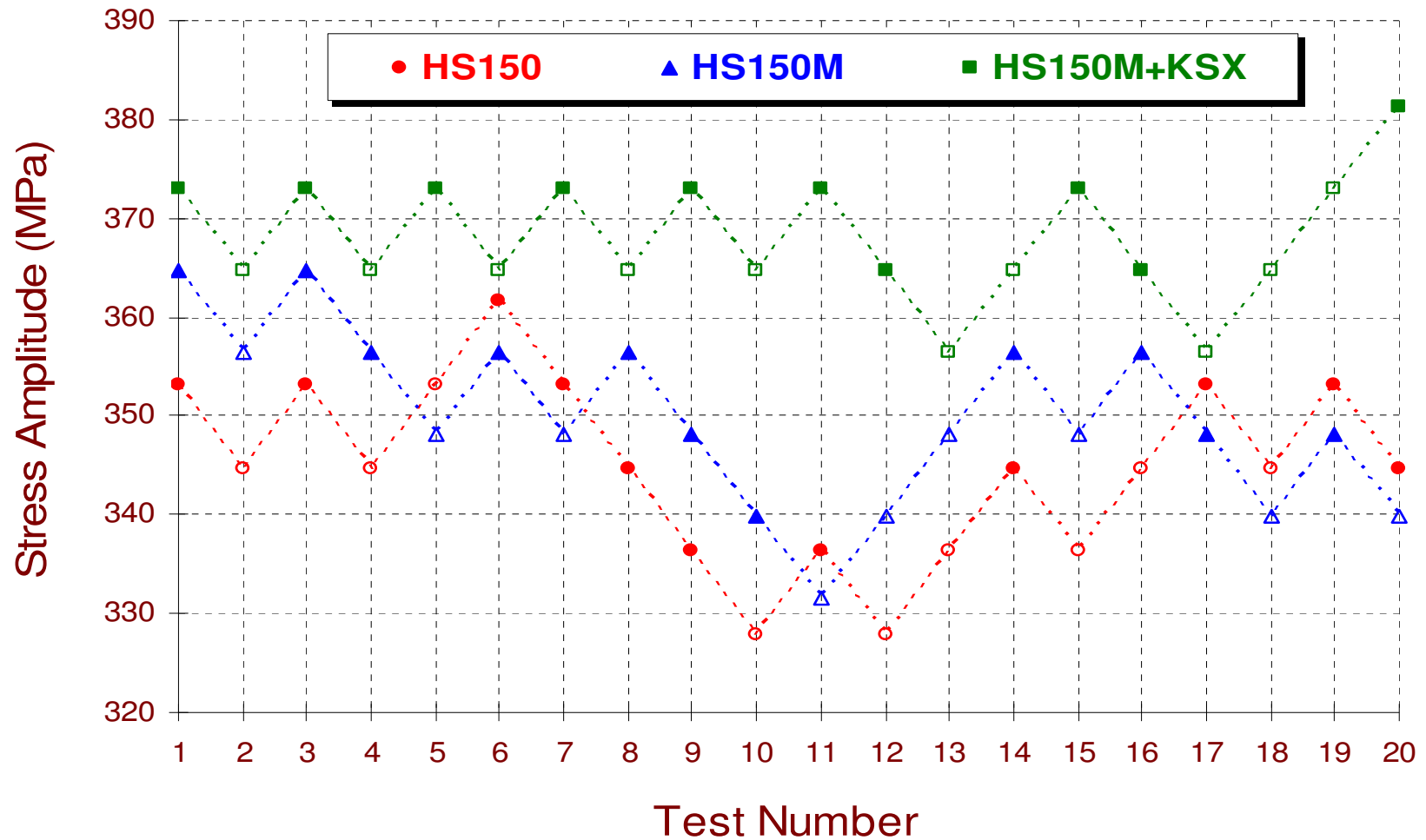
Connecting Rods

Fatigue testing of connecting rods was conducted under the following conditions:

- Constant amplitude
- Axial loading
- Load controlled
- Room temperature
- Stress ratios of $r = -1$ and $r = -2$
- Runout at 10^7 cycles

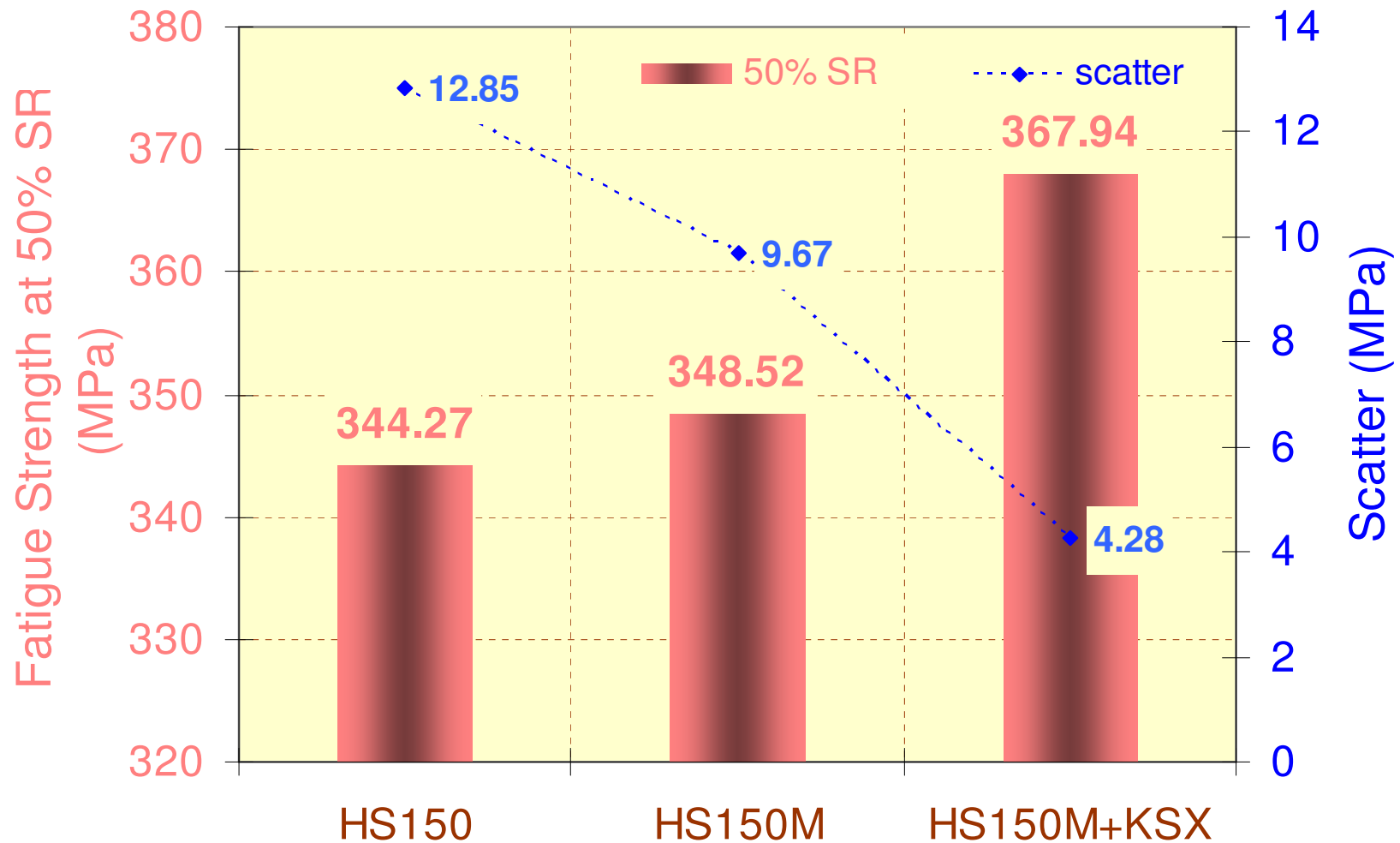
Fatigue Test Results

Powder Forged Connecting Rods, HS150, 10^7 cycles, $r = -1$



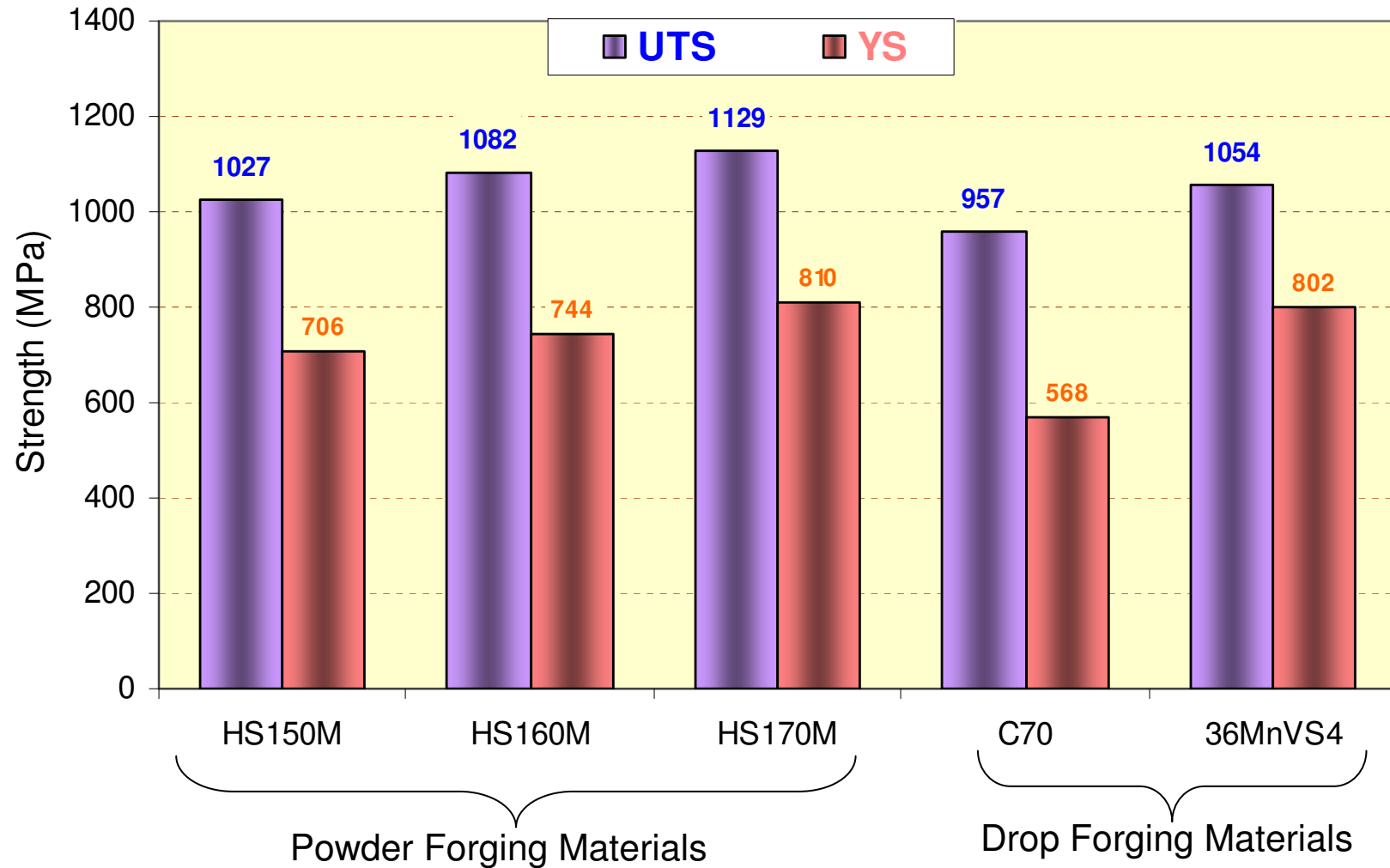
Fatigue Test Results

Powder Forged Connecting Rods, HS150, 10^7 cycles, $r = -1$



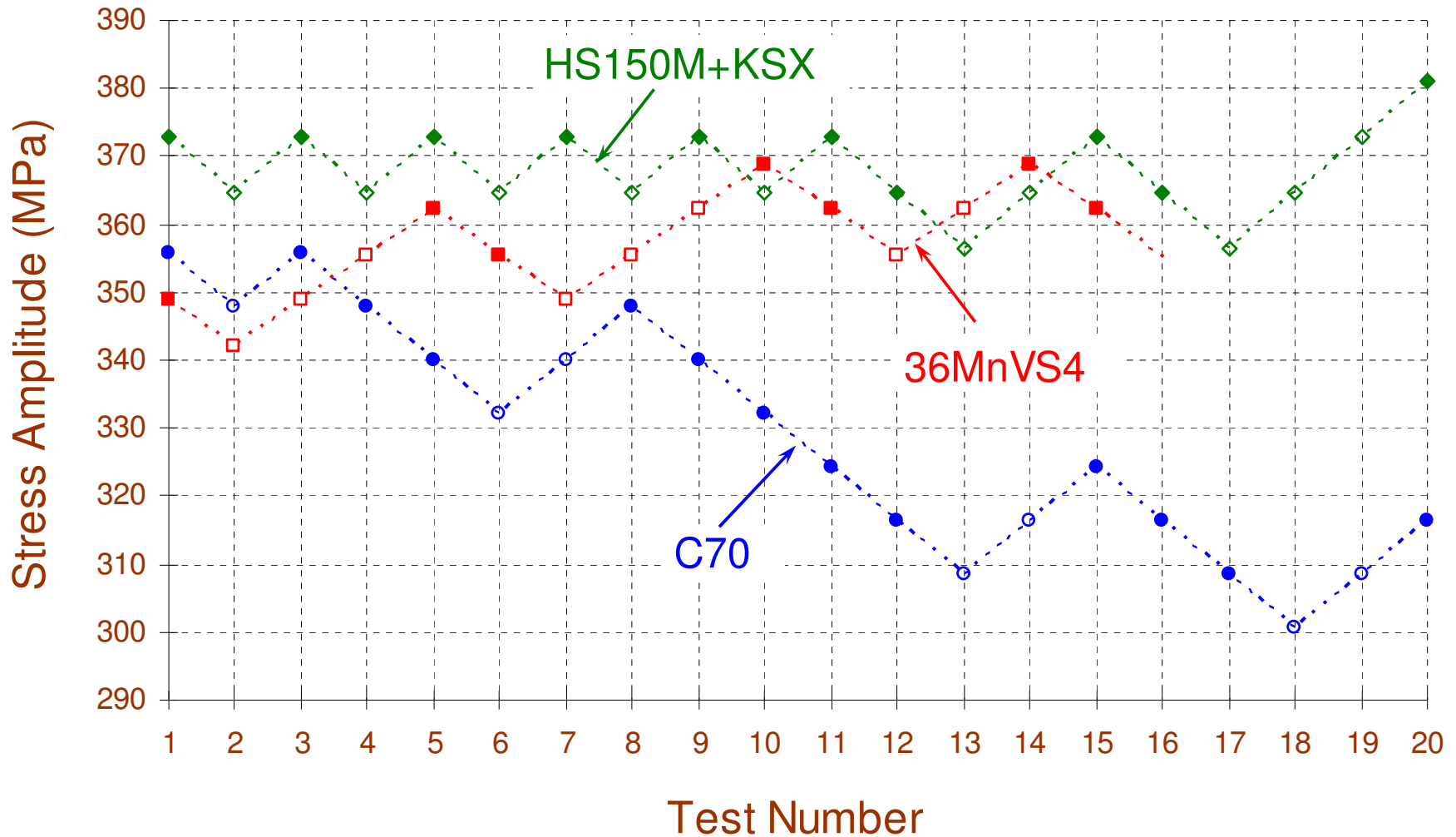
Benchmarking the Industry

Mechanical Properties



Benchmarking the Industry

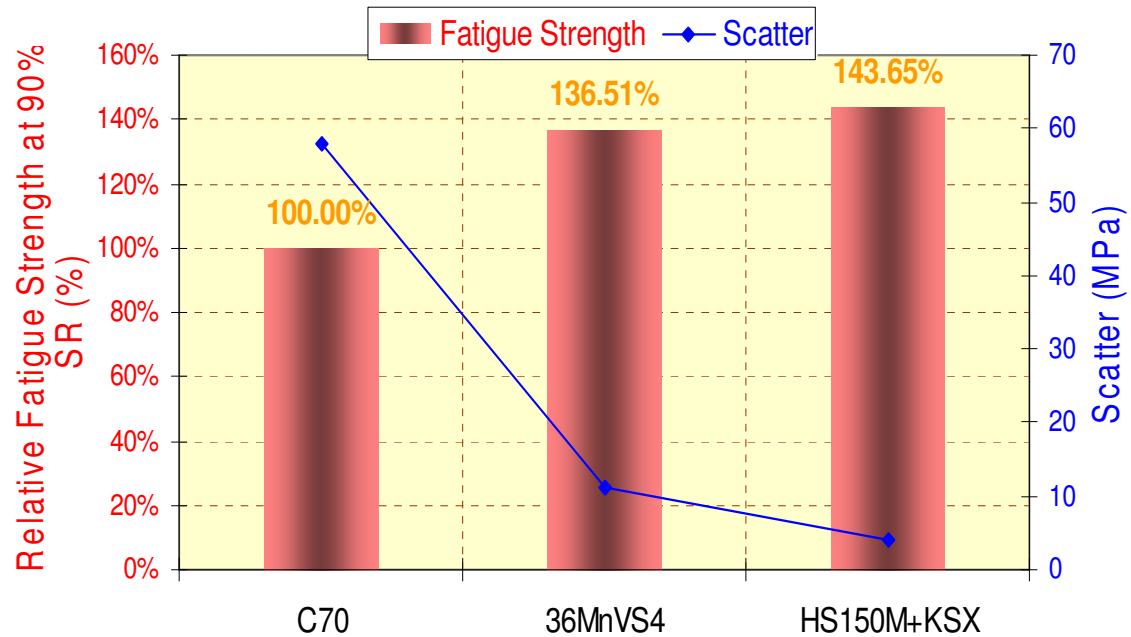
Fatigue Test Results, $r = -1, 10^7$ Cycles



Benchmarking the Industry

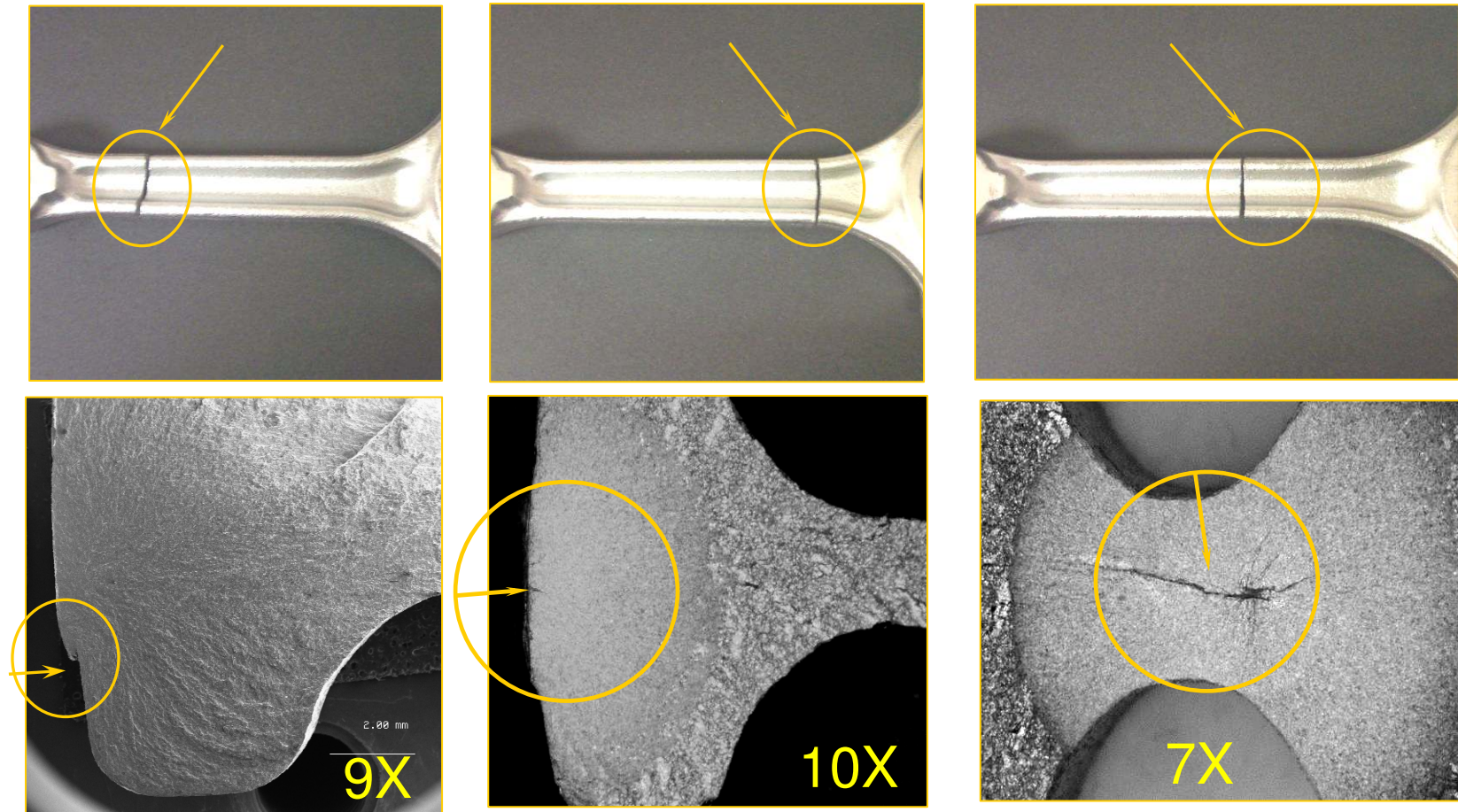
Fatigue Test Results, $r = -1$, 10^7 Cycles

(Mpa)	Powder Forging (HS150M+KSX)	Drop Forging (36MnVS4)	Drop Forging (C70)
Fatigue Strength at 50% SR	368	358	326
Fatigue Strength at 90% SR	362	344	252
Scatter	4	11	58



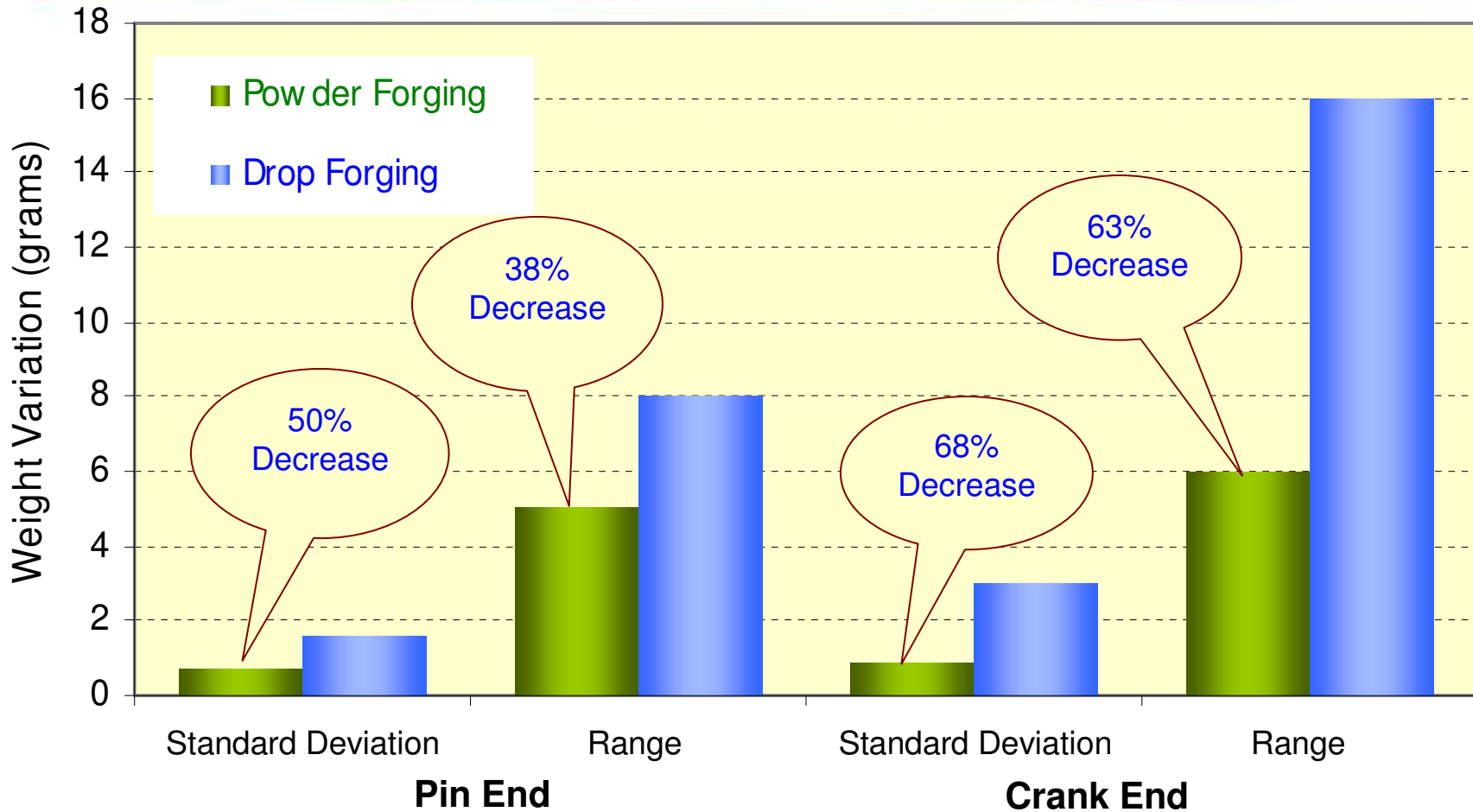
Benchmarking the Industry

Fatigue Testing – Drop Forged C70 Connecting Rods – Failure modes



Benchmarking the Industry

Weight Variation



Powder forging advantage - Reduced balancing moment variation

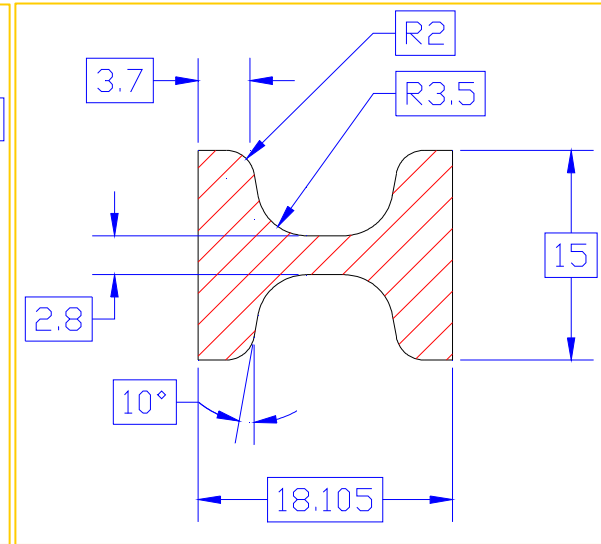
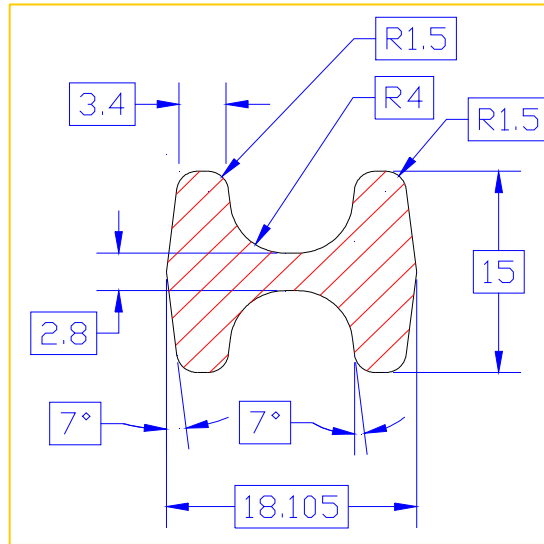
Smaller range and tighter distribution within the range

Mass Reduction Opportunities - Near Net Shape Features

I-Beam Design



Drop Forged
Area = 158.8 mm²
I_{xx} = 2088 mm⁴
I_{yy} = 5675 mm⁴



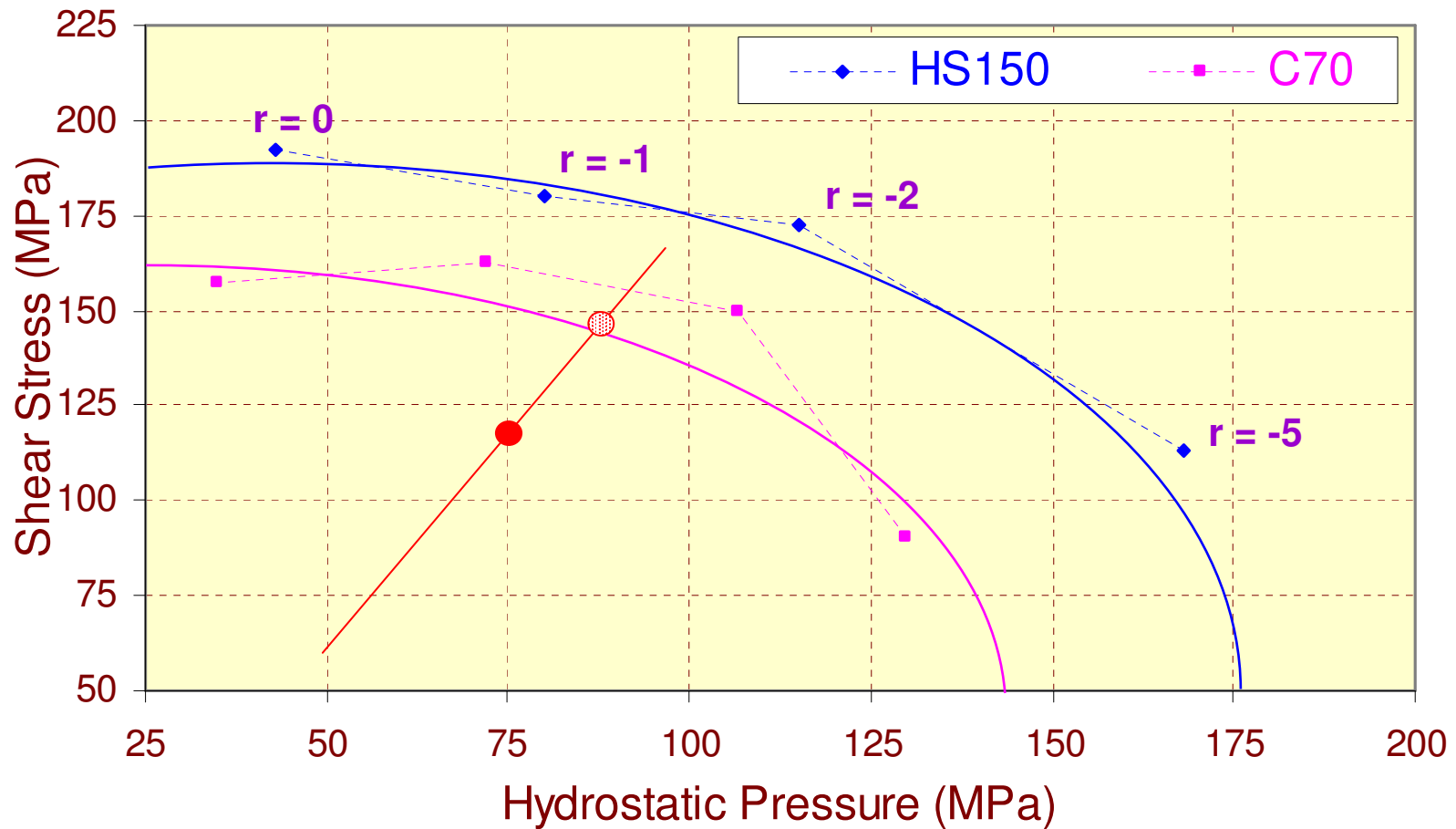
Powder Forged
Area = 158.7 mm²
I_{xx} = 2198 mm⁴
I_{yy} = 6526 mm⁴

Powder Forging Advantage:

- No trim line or draft angle
- 5% higher stiffness in XX-direction
- 15% higher stiffness in YY-direction
- Mass reduction opportunity (reduced cross-section) without loss of stiffness

Mass Reduction Opportunities - Higher Strength Materials

Diesel Application - Case Study – Dang Van Criterion



Conclusion

- **Materials used to manufacture PF connecting rods were optimized resulting in significant improvement in fatigue strength and in more consistent mechanical properties**
- **Fatigue test results from connecting rods clearly showed that PF connecting rods demonstrate higher performance than C70 connecting rods (up to 44%) and compete directly with the newly introduced microalloyed steel (36MnVS4) connecting rods**
- **Near net shape characteristics, inherent to PF, provide ideal I-Beam geometry to maximize the strength to weight ratio, thus resulting in further mass reductions**
- **PF connecting rods have higher material utilization efficiency (due to near net shape forming process), better weight variation control, and better machinability than drop forged connecting rods**