Making High Performance Parts For 32 Years
Our subject today is:

CYLINDER LINERS
FIRST QUESTION?

How many SLEEVEs were in the previous slide??
FORD 4.6L MODULAR
**Note:** Ford Mod motors have a 100mm (3.9382) bore spacing. Our MID max bore is 95mm leaving a gasket seating surface of 5mm. That is the narrowest surface Cometic can make a gasket.
CHARACTERISTICS OF A PERFECT CYLINDER

- WILL NOT CRACK OR BREAK
- STAYS ROUND
- “SEALS” UP
- MINIMUM DISTORTION
- TRANSFERS HEAT
- NO PREMATURE WEAR
- REASONABLE COST
- AVAILABILITY
The Perfect Cylinder
## MECHANICAL PROPERTIES

### DUCTILE IRON

**Chemical Composition:**
- C: 1.70 – 4.50%
- Si: 1.00 – 3.00
- Mn: 0.10 – 1.00
- S: 0.10 Max
- P: 0.10 Max
- Ni: 1.0
- Mg: 0.03

**Tensile Strength** – 100,000 PSI Min. 689 Mpa
**Hardness (Bhn)** – 240 – 290
**Class** – 100-70-03
**Heat Treatment** – Normalized Pearlitic
**Transverse Strength** – 140,000 PSI
**Microstructure** – Tempered Pearlitic
**Matrix** – Ferritic

### CAST IRON

**Chemical Composition:**
- C: 3.10 – 3.50%
- Si: 1.80 – 2.00
- Mn: 0.45 – 0.90
- S: 0.12 Max
- P: 0.12 Max

**Tensile Strength** – 30,000 PSI Min. 207 Mpa
**Hardness (Bhn)** – 196 – 269
**Class** – 30
**Heat Treatment** – n/a
**Transverse Strength** – 2,200 Lb Min.
**Microstructure** – Graphite
**Matrix** – n/a
MATERIAL DENSITY

CAST IRON

STANDARD DUCTILE
# Austenitic Ductile Iron

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Carbon</td>
<td>3.00</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.50-3.00</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.08</td>
</tr>
<tr>
<td>Nickel</td>
<td>18-22</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.75-2.75</td>
</tr>
</tbody>
</table>

## Additions

- Additions of 0.7 - 1.0% molybdenum will increase the mechanical properties above 800 °F (425 °C)
- B not intentionally added
# Austempered Ductile Iron

## ASTM A 897 / A 897M

<table>
<thead>
<tr>
<th>GRADE</th>
<th>MIN. TENSILE STR.</th>
<th>MIN. YIELD STR.</th>
<th>ELONGATION</th>
<th>IMPACT ENERGY</th>
<th>HARDNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPa</td>
<td>Ksi</td>
<td>MPa</td>
<td>Ksi</td>
<td>%</td>
</tr>
<tr>
<td>125/80/10</td>
<td>125</td>
<td>80</td>
<td>125</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>850/550/10</td>
<td>850</td>
<td>550</td>
<td>150</td>
<td>100</td>
<td>7</td>
</tr>
<tr>
<td>150/100/7</td>
<td>150</td>
<td>100</td>
<td>150</td>
<td>100</td>
<td>7</td>
</tr>
<tr>
<td>1050/700/7</td>
<td>1050</td>
<td>700</td>
<td>175</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>175/125/4</td>
<td>175</td>
<td>125</td>
<td>200</td>
<td>155</td>
<td>1</td>
</tr>
<tr>
<td>1200/850/4</td>
<td>1200</td>
<td>850</td>
<td>200</td>
<td>155</td>
<td>1</td>
</tr>
<tr>
<td>200/155/1</td>
<td>200</td>
<td>155</td>
<td>230</td>
<td>185</td>
<td>-</td>
</tr>
<tr>
<td>1400/1100/1</td>
<td>1400</td>
<td>1100</td>
<td>1400</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td>230/185/-</td>
<td>230</td>
<td>185</td>
<td>230</td>
<td>185</td>
<td>-</td>
</tr>
<tr>
<td>1600/1300/-</td>
<td>1600</td>
<td>1300</td>
<td>1600</td>
<td>1300</td>
<td>-</td>
</tr>
</tbody>
</table>
CAST IRON FEATURES

- INEXPENSIVE
- EASY BREAK-IN
- RELATIVELY LONG LIFE
- AVAILABLE FROM MANY SOURCES
- EASY TO INSTALL
- EASY TO HONE
- WIDE INDUSTRY KNOWLEDGE AND EXPERIENCE
- BRITTLE WITH LITTLE ELONGATION
- RELATIVELY EASY TO MACHINE
- GOOD HEAT TRANSFER
- CHEMISTRY INEXPENSIVE, i.e. SCRAP
DUCTILE IRON FEATURES

- HIGH SURFACE HARDNESS
- HIGH DUCTILITY
- HIGH RESISTANCE TO SHOCK
- LONG LIFE CYCLE
- THERMALLY STABLE
- MODERATE HEAT TRANSFER
- MORE DIFFICULT TO HONE
- MORE DIFFICULT TO MACHINE
- POSSIBLE VARIANCES IN HARDNESS (supplier issues)
- MAY BE HEAT TREATED
- WIDE AREA OF PROPERTIES, HARDNESS, DUCTILITY, etc.
DUCTILE IRON – AS CAST & CENTRIFUGAL CAST

**AS CAST**
- Possible occlusion
- Variance in pearlitic distribution
- Good for irregular shapes
- Competes with cast steel
- Versatile applications
- Easy to machine
- Not best procedure for cylinder liners

**CENTRIFUGAL CAST**
- Easy to control density
- Impurities slung outward & removed in machining
- Compacting material avoids occlusions
- Variable speed rotation allows “tuning” of centrifugal cast blanks
- Rotational dies able to be water cooled
- More economical for cylinder liner production
- Higher production rate
CASTING PROCESS
## Ductile & Austenitic Iron Chemistry

<table>
<thead>
<tr>
<th>Mechanical Property</th>
<th>Forged Steel</th>
<th>Pearlitic Ductile Iron</th>
<th>Grade 150/100/7 ADI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength, ksi (mPa)</td>
<td>75 (520)</td>
<td>70 (480)</td>
<td>120 (830)</td>
</tr>
<tr>
<td>Tensile Strength, ksi (mPa)</td>
<td>115 (790)</td>
<td>100 (690)</td>
<td>160 (1100)</td>
</tr>
<tr>
<td>Elongation %</td>
<td>10</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Hardness, Bhn</td>
<td>262</td>
<td>262</td>
<td>286</td>
</tr>
<tr>
<td>Impact Strength, ft-lb (joules)</td>
<td>130</td>
<td>40</td>
<td>120</td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td>3.70%</td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
<td></td>
<td>2.50%</td>
</tr>
<tr>
<td>Manganese</td>
<td></td>
<td></td>
<td>0.28%</td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
<td>as required</td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
<td></td>
<td>as required</td>
</tr>
<tr>
<td>Molybdenum</td>
<td></td>
<td></td>
<td>only if required</td>
</tr>
</tbody>
</table>
HOW TO GET EXCEPTIONAL DUCTILE IRON

- PURE PIG IRON BASE
- PROPER CHEMICAL MIX
- CONTROLLED LADLE TEMPERATURE
- CONTROLLED INNOCOLATION PROCEDURES
- CONTROLLED “DEGAUSING” OF LADLE
- PROPER POURING TECHNIQUE
- ESSENTIAL TIME CONTROL
HOW TO GET EXCEPTIONAL DUCTILE IRON

PIG IRON:

4 - 5 % CARBON

0.4 - 1.0 % SILICONE

0.03% OR LESS SULFUR

0.15 % OR LESS PHOSPHORUS
MPA X $145.0 = PSI$
MPA X $0.145 = KSI$
CYLINDER INTEGRITY

- SHAPE OF CYLINDER
- CYLINDRICAL UNIFORMITY
- SUFFICIENT COOLING
- MASS OF CYLINDER
- METHOD OF INSTALLATION
- RATIO OF BORE TO STROKE
- CYLINDER MATERIAL
- CYLINDER HARDNESS
HORSEPOWER BASICS

PROCESS
“OTTO THEORY”
SUCK
SQUEEZE
BANG
BLOW

EFFICIENCY
CYLINDER FILLING
FLAME PROPAGATION
PRESSURE CURVES
CYLINDER SCAVEGING

LOSSES
PUMPING
THERMAL
FRICITION
DISTORTION
NEGATIVE EFFECTS

CAUSES OF CYLINDER DISTORTION
Heat Distortion

Red = Max Distortion Area
Yellow = Moderate Distortion Area
Green = Low Distortion Area
von Mises Yield Criterion

- High Stress
- Moderate Stress
- Low Stress

Values derived using wall thickness, tensile strength, and stress

\[ f \left( J_2 \right) = \sqrt{J_2 - k} = 0 \]

\( f = \text{function} \)
\( J = \text{Plasticity Theory} \)
\( k = \text{critical value} \)
OFF AXIS DISTORTION
DEFORMATION

The Distortion Cycle
The Distortion Cycle

Estimated cylinder pressure at 20 ATDC

Street: 5000 - 15,000 PSI

Drag
Normally Aspirated: 15,000 - 25,000 PSI

Boosted: 25,000 - 40,000 PSI

Top Fuel: 60,000 - 80,000 PSI
Heat Transfer Over Time - Success
Heat Transfer Over Time - Failure
A Super Charger Named Pete
WATER JACKET
NOT IN OUR SOLUTIONS INDEX

- CAMS
- FUEL DELIVERY
- IGNITIONS
- PISTON DESIGN
- RING DESIGN
- HONING
SOLUTIONS

MATERIAL

MASS

STRUCTURE
SOLUTIONS

- STRONGER MATERIAL
  - Steel - Coated
  - Ductile Iron
  - ADI

- ADD STRUCTURE
  - High Flanges & Flats

- WET SLEEVING

- COOLING SOLUTION
  - Flow Porting
  - Reverse Flow

- ADD MASS
  - Decrease Bore
  - Increase Stroke
FORD MODULAR M.I.D.
FORD 4.6L MODULAR
FORD 4.6L MODULAR
FORD 4.6L MODULAR
WHERE PERFECTION IS
THE MINIMUM