Quality of ductile iron

It is in the eye of the beholder

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THORS
What is quality? Properties? Can we quantify it?

• Soundness – gas and shrinkage
• Absence of inclusions
• Absence of carbides – chill, inverse, grain boundary
• Graphite shape, Graphite size, amount of graphite (area/volume)
• Distribution of graphite– random not preferred orientation
• Matrix – ferrite pearlite - distribution
• Hardness
• T/Y/E plot
• Quality index - ?
• T/H ratio - ?
• Surface properties???
D.L. Crews (1974), based on Siefer and Orths (1970) proposal, using ASTM minimum properties as base

Pay attention to the points represented here by small circles throughout this presentation.
Carl Loper, Jr. and R.M.Kotschi

- Made the relationship linear
- Base is same as ASTM minimum properties curve – based on earlier ductile production practice
- Which had higher silicon and nickel levels than current production
- This reflects the difference between ASTM and the ISO property curve
- 65-45-12 is the most used spec for ductile – every one made room for that one.
What does quality mean when there are so many combinations of chemistry, section size and processes?

• Can quality be higher than 100%?

• Is quality measured against an average or maximum potential possible?

• Like nodularity – max is 100% spheroidal shape and comparison to it.

• For ductile iron – how a customer can compare the quality from one supplier to another? – Is 100% nodularity enough?

• Castings are designed for the lowest common denominator – hence the mediocre conditions pass. Should it be? To reduce weight and compete with light weight materials, what can we do assure the designers, the properties are there consistently with minimal variations?
If we are going to use a standard for comparison, which one should we use? Have we dumbed down the specs?
Yield versus elongation-65-45-12 grades

<table>
<thead>
<tr>
<th>Yield KSI</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Br</td>
</tr>
<tr>
<td>cc</td>
<td>m-m</td>
</tr>
</tbody>
</table>
A tale of two samples.

T = 76.7 ksi
Y = 51.2 ksi
E = 4.8%
HB = 207
QI = 28.2
T/H = 0.26

T = 69 ksi
Y = 43.3 ksi
E = 20%
H = 170
QI = 95
T/H = 0.285
What is wrong with the anomalous point? – the one at left. Looks okay to most people – unless some property fails to meet requirements – like elongation here? There were no obvious foundry defects.
Etched structure – look at the path of failure

Near fracture

Across the fracture
How to assign quality index?

• Quality index# = \( \frac{T^2}{1000} \times E \) (T = tensile in ksi, E = % elongation)
• QI = \((76.7)^2 \times 4.8)/1000 = 28.24\) - Is the ductile that bad?
• \( \hat{T}.S = 36.8 + \frac{126}{(E)^{0.61}} \) (ASTM minimum property graph) (-12%)
• \( T/H = (76.7/207) \times 0.703 = 0.260 \) (Range for good ductile 0.29 -0.33)
• HB proportional to compression strength (HB*9.81 = MPa)
• Tensile strength is a fraction of compression strength
• Gray irons \( T/H = 0.1 - 0.15 \)

The point on the right: T-69ksi, Y-43.3ksi, 20%E, 170HB ( QI =95.22, +15%, T/H =0.285 )

No Bake molds, 1” Y block test bar inside the mold attached to casting

C = 3.56  
Si = 2.4  
Mn = 0.47  
Ni = 0.7  
Cu = 0.14
Pearlite is not contributing to tensile even as it influences hardness. Ferrite is continuous hence elongation and yield strength is corresponds to ferrite properties. When ferrite is discontinuous, average takes over.

\[
\text{Ferrite percent} = 85, \\
\text{Hardness} = 147 \\
\text{Pearlite} = 15 \\
\text{Hardness} = 320 \\
\text{Then bulk or measured hardness} = 0.85 \times 147 + 0.15 \times 320 = 125 + 48 = 173 \\
\text{Tensile and yield will correspond to ferrite hardness of 147}
\]
What are the reasons for the increase in the T/H ratio with Tensile? Why mean value of T/H for 80/55/06 higher than 100/70/03 and 65/45/12, or is it?
Different grades, Why the shift?
Properties are not linear – all the way – what is the maximum potential for given hardness?

![Graph showing properties vs hardness](image)

**Figure 6.** Ultimate Tensile Strength vs. Brinell Hardness for the Entire 53 Foundry Sample Set

Slope of line, T/H = 0.309
Highest, T/H = 0.364
Lowest, T/H=0.276
Figure 1. Correlation of yield strength with total elongation in the numerous samples tested in Project 46.
What is the potential for a given chemistry?
For as cast ferritic/pearlitic ductile iron

• Potential for what? 1. chemistry, 2. cooling rate. (nodularity, carbides)

• If chemistry is correlated to certain ferrite/pearlite depending on cooling rate, the result is proportional to hardness.

• Can then potential be estimated for that hardness – T, Y, E?

• From this potential various casting sections with various cooling rates and hardness can be expected to produce certain property values?

• Ductile properties app helps to determine the pearlite ferrite for a given section size, and strength values form that hardness. It can be fine tuned to determine the quality index?

• Start with eutectic CE (C+0.25Si = 4.3)
What are the reasons for variability?

- Chemistry?
- Cooling rate?
- Inoculation?
- Nodule count, size distribution?
- Austenite grain size?
- Matrix – distribution – what factors affecting?
- How to take advantage of segregation of Mn?

- Melt quality affecting casting quality
- Inoculation practice – When and where at what temperature, what alloy and how much –
- Gating - dissolution of inoculants and solidification rate of castings
What next?

• What is the present state of quality?

• Audit of existing practices
  • Between plants, between grades, between processes Test bars – size and measurement variations
  • Common for testing (like sand tests DIS Project #40, Survey of Green sand properties)
  • Microstructure correlation to mechanical properties from the test bars and quality to processing conditions
  • Identify and recommend best practices