Characterization of Microstructure and Composition Controlling Fracture Split Behavior in Microalloy Forging Steels

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Materials Engineering
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Caterpillar, some time after a change in forging heats, found that fracture splitting manufacturing yields differed with changes in heat. A study was performed to assess the discrepancy through analysis of the microstructure and the fracture behavior of fractured Charpy v-notch bars. It was found that larger prior austenite grains and less proeutectoid ferrite corresponded to the best fracture behavior. Also, parts that had problems fracturing tended to have larger shear lips than the parts that did not have problems.

This work is sponsored by Caterpillar, Lafayette, IN

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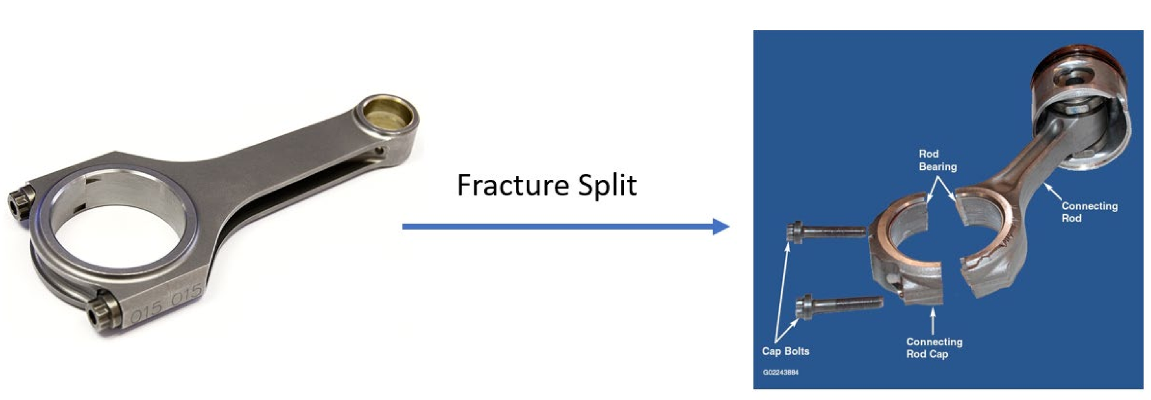
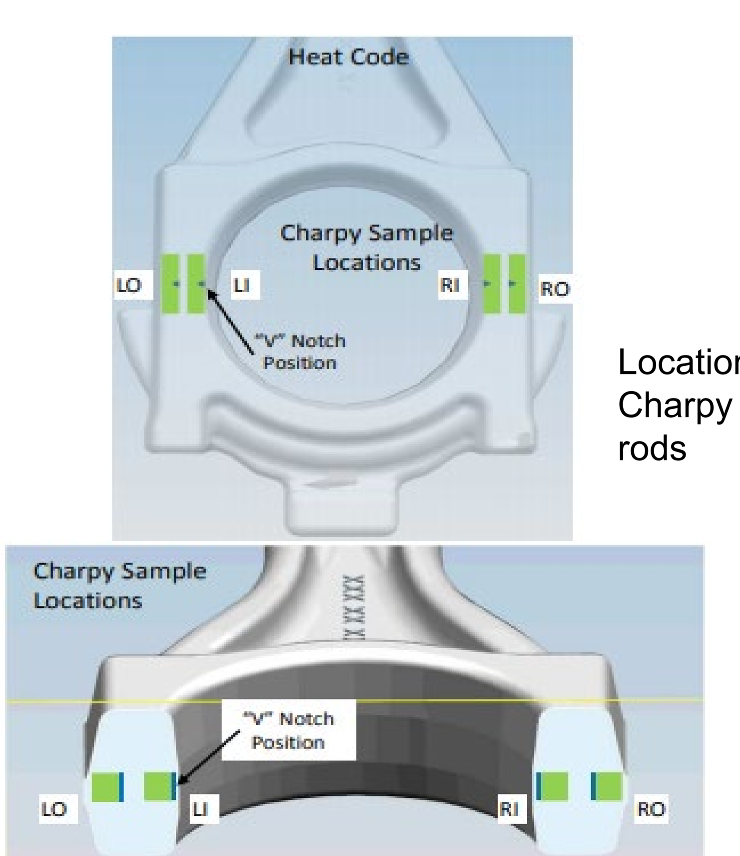
Project Background

Caterpillar uses fracture splitting to manufacture the connecting rods in large engines- using a wedge to completely fracture the bearing starting from two laser cut notches so that it can be bolted together around the crankshaft. These large engine connecting rods require a yield strength significantly greater than other conventionally smaller fracture split connecting rods. To achieve this strength they are made from a High Strength Low Alloy (HSLA) steel, which uses certain microalloying elements such as vanadium to form carbides that increase strength by grain size refinement.



Left: Brian Crower Sportsman Connecting Rod Set - VQ35DE / VQ35HR
Retrieved from https://www.z1motorsports.com
Right: Fracture-split Connecting Rods
"No, That's Not a Broken Part." (2014, October 20). Retrieved from https://mitchell1.com

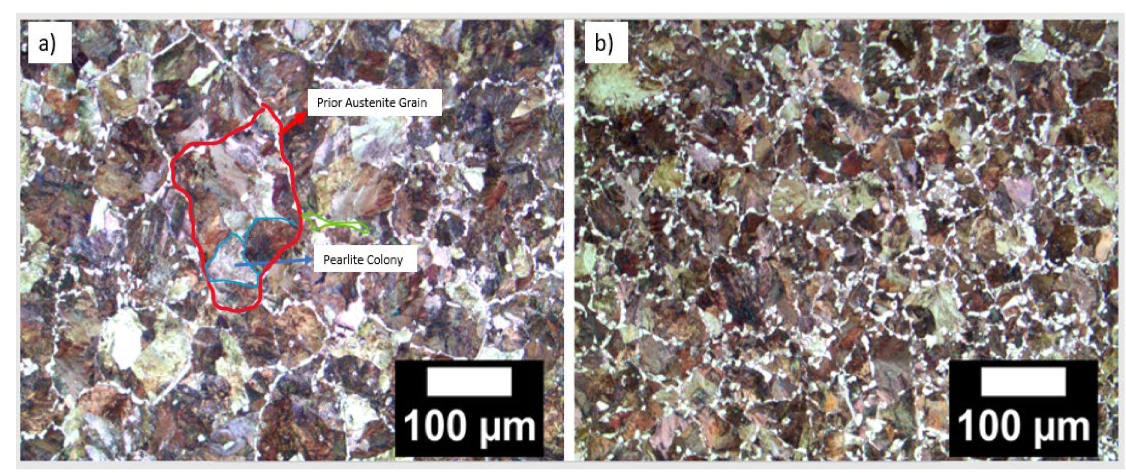
Room temperature Charpy impact testing had already been conducted, the results of which did not have enough resolution for useful conclusions. These fractured Charpy bars were provided for analysis, of both the middle of the bar and the fracture surface.



Location Caterpillar retrieved Charpy bars from in connecting rods

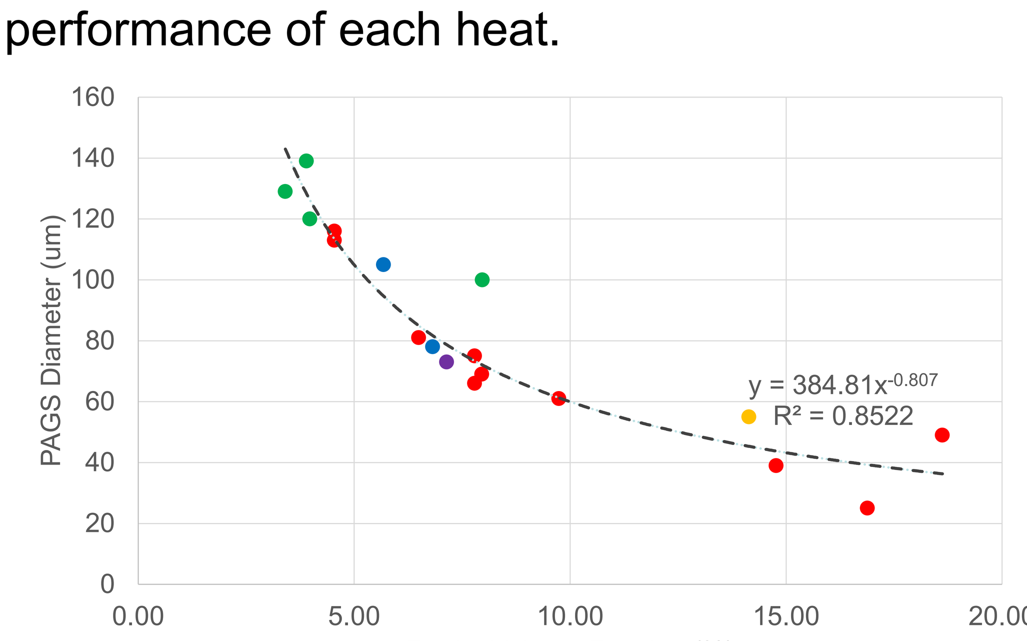
Quantitative Microstructural Analysis

Selected Charpy samples were cut, and the face parallel to the fracture surface was mounted, polished, analyzed by optical microscopy.



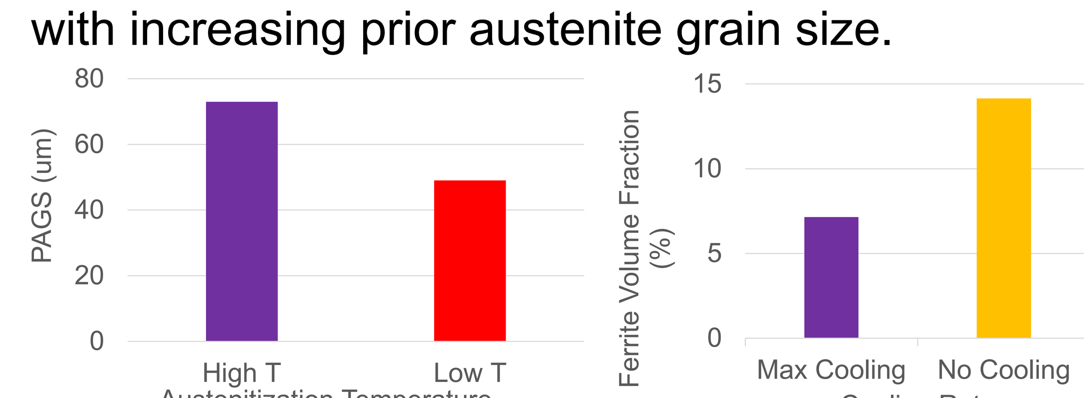
Optical micrographs of: a) a sample from the good heat, Forging Process A-OK and, b) a sample from the problem heat, Forging Process B-Problems.

The main characteristics analyzed on were prior austenite grain size (PAGS), pearlite colony size, and the relative amounts of proeutectoid ferrite and pearlite microconstituents, and the relationships between these features and the fracture performance of each heat.



Plot of the PAGS versus proeutectoid ferrite volume fraction

The proeutectoid ferrite volume fraction decreased with increasing prior austenite grain size.



Average PAGS based on austenitization temperature. High T is High-High and High-Low, while Low T is the other three heats.

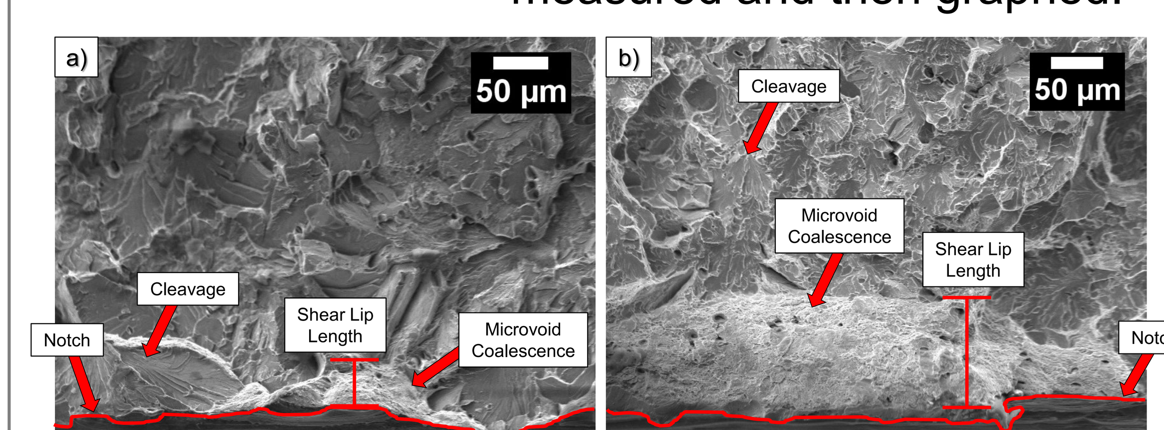
Proeutectoid ferrite volume fraction for the different cooling rates at high austenitization temperature.

Fractographic Characterization

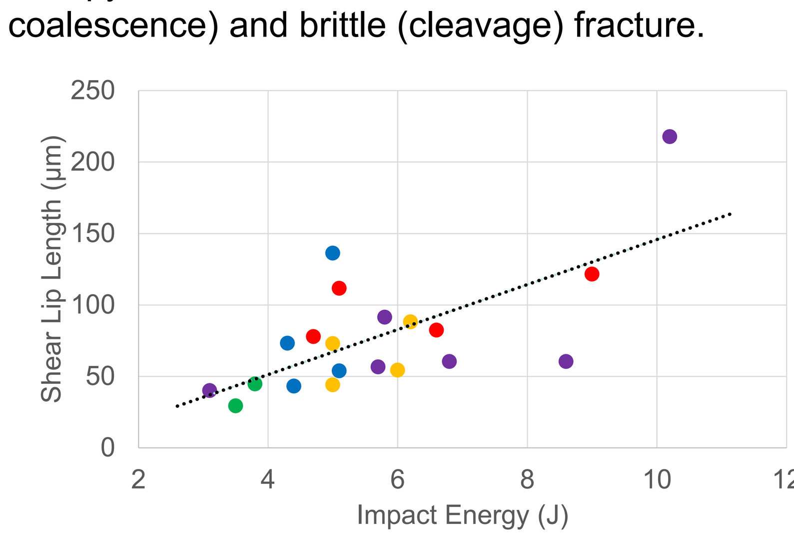
Based on the possible appearance of a shear lip, it was determined that further investigation of the fracture along the Charpy notch was necessary. The samples were cleaned with acetone and then placed in a scanning electron microscope (SEM) to take five secondary electron images per sample.

Image of a fractured Charpy bar, with the red squares indicating the locations that the five SEM images were taken for each sample.

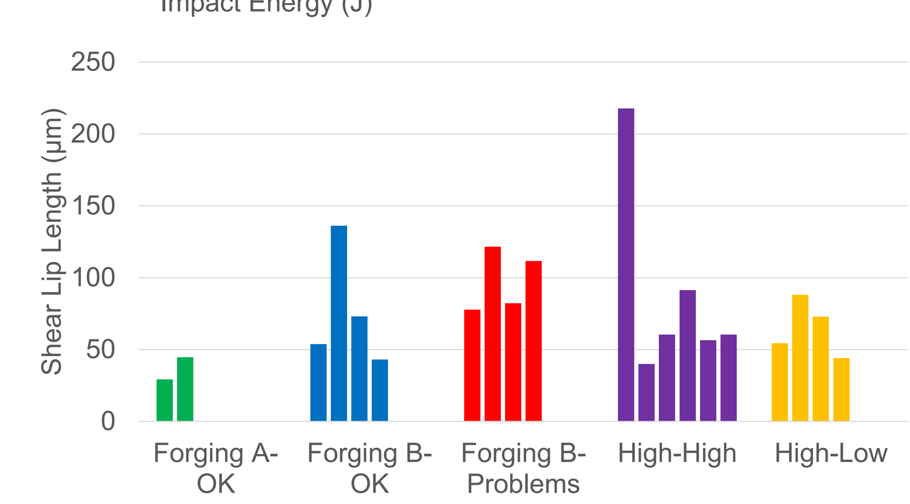
Where there were regions of ductile fracture along the notch, the maximum length of the shear lip, perpendicular to the Charpy notch, was measured and then graphed.



SEM images of the fracture surfaces of: a) a sample from Forging Process A-OK and, b) a sample from Forging Process B-Problems. The maximum shear lip lengths have been marked, along with the Charpy notch and some characteristic areas of ductile (microvoid coalescence) and brittle (cleavage) fracture.



Maximum shear lip length plotted against the previously measured room temperature Charpy impact energies. The line is meant as a guide for the eye.



Maximum shear lip length for different heats.

Problem

When the material used in large engine connecting rods experienced a change in heat, some of the connecting rods began to fracture incompletely during fracture splitting. The purpose of this project was to investigate the relationships between microstructural characteristics of the metal used in different heats and the corresponding fracture performance, with the goal of determining a method to predict how well a given heat will fracture.

Sample Type Name	Description
Forging Process A-OK	Samples from the previous heat
Forging Process B-OK	Samples from the new heat prior to any problems
Forging Process B-Problems	Samples with the same forging procedure as Forging B-OK but that had significant fracture splitting issues
High-High	Forging trial with a high austenization temperature and high cooling rate
High-Low	Forging trial with a high austenization temperature and low cooling rate

Descriptions for the different sample designations and color codings to be used in this poster.

Conclusions

Optical microscopy demonstrated that a higher austenitization temperature lead to a larger prior austenite grain, whereas a lower cooling rate resulted in a higher ferrite volume fraction. The samples with better fracture performance had a greater PAGS and a lower proeutectoid ferrite volume fraction. The SEM fractography, specifically the measurements of the shear lip length, largely correlated with the Charpy impact energy measurements previously taken by Caterpillar. There was variance in the different samples, but the length of the shear lip did tend to correlate with the quality of the fracture splitting. However, extreme variance within the same forging heats such as High-High and Forging B-OK, indicated that there were likely factors other than a microstructural correlation, possibly factors such as elemental segregation, driving the differences in fracture.

Acknowledgements

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Recommendations

One possible future avenue of research could include Charpy impact testing at higher temperatures to facilitate higher resolution of impact energy and ductile fracture measurements. Another approach could be an alternative test, such as a high strain rate tensile test.