Repairing Cracks in Cast Iron using Friction Stir Welding

Prepared by:
Josiah Douglas Ochieng Oduor

Faculty Advisors:
Dr. Michael West

Dr. Michael West
Director, SDSMT Advanced Materials Processing Center

Dr. Alfred Boysen
Professor, Department of Humanities

Program Information
National Science Foundation
Grant #0852057

Research Experience for Undergraduates
Summer 2010

South Dakota School of Mines and Technology
501 E Saint Joseph Street
Rapid City, SD 57701

Abstract

The objective of this work is to evaluate the feasibility of repairing defects in gray cast iron through friction stir processing (FSP). In fusion welding the graphite flakes in cast iron act as stress concentrations on the material causing it to become brittle and crack (4), however in friction stir welding (FSW) the material is not melted and does not experience this brittle nature. The process of friction stir welding grade 40 gray cast iron by itself is difficult because the graphite flakes in the cast iron act as a lubricant not allowing enough frictional heat to join the two materials (5). A 1006 steel cover plate and more forge force were used in order to help create enough frictional heat to create a more effective weld.

Introduction

Gray cast Iron is often used in the making of diesel engine blocks. In certain cast iron diesel engines cracks have initiated in the cast iron blocks, causing leaks and eventually requiring the owner to buy a new engine or have the cracked engine repaired. The purpose of the research is to evaluate the effects of repairing the engine blocks using friction stir welding. Gray cast iron contains an abundance of graphite flakes which act as a lubricant which does not allow enough frictional heat to enter the welding process. The use of a steel cover plate to interact with the graphitic microstructures in order to allow more frictional heat to while welding, will be evaluated. Previous work done on gray cast iron without a steel cover plate was unsuccessful.

The weld used with in this paper is a 9 inch long weld consisting of 3 different sections. The material is a 0.5 inch gray cast iron with a 0.06 inch 1006 steel cover plate. The weld is approximately 0.2 inches down in the cast iron. The three different sections are as follows: a 3 inch 3330 lbs force forge weld, a 3 inch 3000 lbs force forge weld, and a 3 inch 2700 lbs force forge weld. All welds ran at a constant 1000 RPM and a constant 0.25 inches per minute.

Broader Impact

The ability to friction stir weld grade 40 grey cast iron defect free and without the loss of expensive pin tools could help change the automotive industry. Grey cast iron is often used in the production of diesel engines, since diesel engines require greater pressure resistance than regular engines. When diesel engines crack the first thought isn't to repair the engine, but to buy a new one. With the ability to friction stir weld grey cast, cracks in grey cast iron could be FSW back together instead of having to replace and engine block. Although the initial cost of a Friction stir welder is high, the money saved from FSW-ing cracked engines would surpass the cost of replacing whole engines.

Equipment

- LECO PR-25 Mounting press
- LECO BG-32 Sander
- LECO CM-24 Abrasive saw
- LECO Spectrum System 1000 Polishing machine
- SHARP TMV Milling Machine
- MTS ISTIR 10 Friction Stir Welding Machine
- Kobalt 1/4 Angle Rotary Tool LGA- 1143

Procedure

Mounting, Polishing and Etching

Samples of both a parent-material, grade 40 grey cast iron and a FSW-ed Grade 40 grey cast iron with a steel cover plate are initially cut out using a DoAll band saw using a silicon carbide blade. These samples are then machined down using an aluminum oxide abrasive saw. These samples are then mounted in Bakelite using a LECO PR-25 mounting press. After the samples are mounted, they go through a series of polishing using a range of 80 to 1200 grit silicon carbide on LECO BG-32 and LECO Spectrum System 1000 polishing machines. Then a diamond suspension solution is used on Nylon paper from a range of 9 microns to 1 micron. The samples are cleaned off in between every stage of polishing using a soap and water solution then flushed with water and finally dried with compressed air. The samples are then etched using a 2% Nital solution for approximately five seconds either by immersion or swiping with a cotton swab. The microstructures and macrostructures of the samples are then examined using a microscope and macro scope.

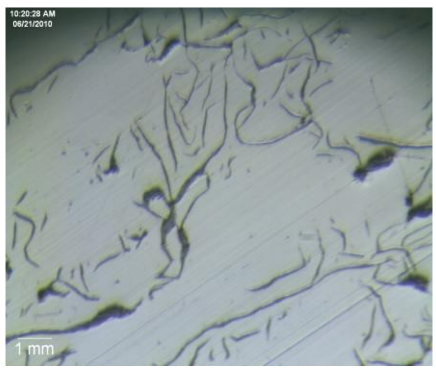

Fig 1. The microstructure of grey cast iron.

Tensile Sample Machining

Tensile testing samples out of steel and cast iron were both cut and machined out for this project. Steel samples were machined for the purpose of gaining experience for milling and machining tensile samples. They were machined out of a quarter of an inch steel plate and milled to a thickness of 0.1875 inches and a length of four inches using ASTM standards.

The cast iron tensile samples were cut using a DoAll band saw then faced down to the thickness of 0.1875 inches using a milling machine. The cast iron samples first had to have the steel cover plate machined off using the dog-bone tensile shape was then created using a preset jig meeting the ASTM standards. (1)

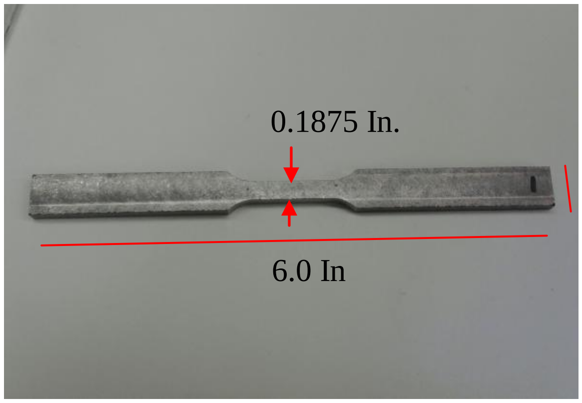

Fig 2. Cast Iron Tensile Sample

Tensile Testing

The tensile testing on the parent-material, grade 40 grey cast iron, was done using a MTS 810 Material Testing Machine. The steel dog bones were tested first in order to warm up the machine and make sure the data was being collected correctly. After the steel samples were tested the cast iron parent material and FSW samples were tested. Prior to testing, a 1 inch extensometer was placed within the gauge length of the tensile to measure the elongation up to a preset elongation value of 0.02 percent. Upon reaching this preset value, the test was paused, the extensometer was removed from the sample and the test was resumed. They were tested till fracture and the data was then recorded.

Welding

Before welding a heating anvil is placed on the welding table and heated up to approximately 200° C in order to have the cast iron heated uniformly. The anvil is made of a range heating element surrounded by one inch steel walls all around. The steel is used for support during welding. The anvil uses conduction heating to heat the cast iron above it.

Fig. 3: Heating anvil [3]

The cast iron and steel plates are cleaned using a Kobalt 1/4 Angle Rotary Tool to sand the plates down and remove surface contaminates. They are then whipped down with alcohol to remove excess contaminates. The steel cover plate is then centered and clamped down on top of the cast iron plate. The welding head is then positioned to obtain a zero and a maximum distance for the weld. The weld proceeds at 0.25 inches per minute (IPM) and at 1000 revolutions per minute (RPM).

Scanning Electron Microscope (SEM)

A pulled tensile sample and a mounted cast iron sample were both analyzed in the SEM. Both samples were prepared by using two sided conductive tape to attach them to a stage, which was then in inserted into the SEM. These samples were analyzed to get high quality images and to perform Electron Dispersive Spectroscopy (EDS). EDS was performed on the fracture surface of a broken FSW tensile sample, within the mixed steel region above the nugget and within the nugget of a mounted grey cast iron sample.

Results

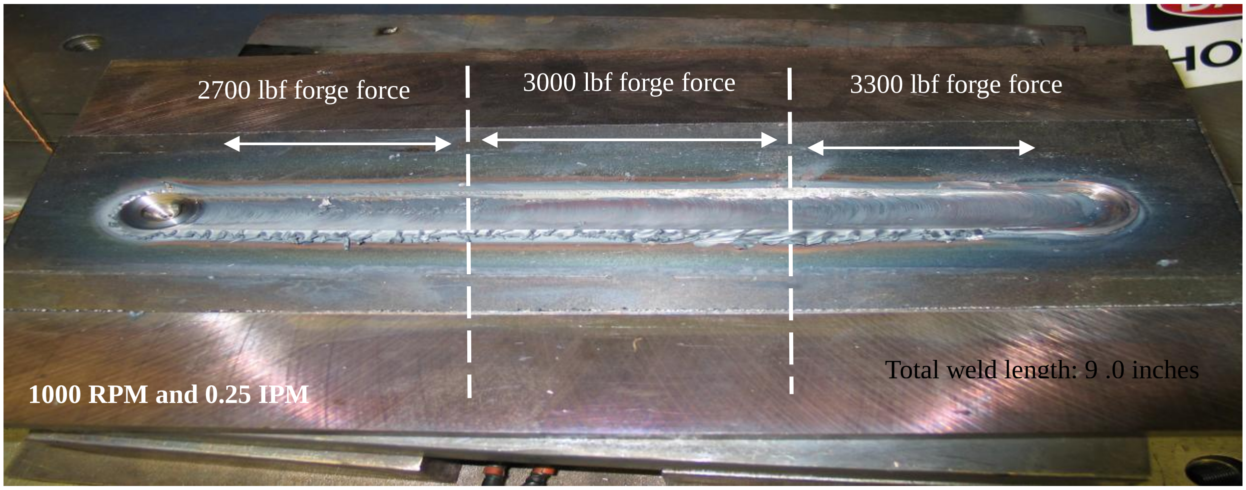

Fig. 4: Weld parameters [Picture taken by Nick Smith]

Welds

A 9 inch weld welded with 2700, 3000, and 3300lbf forge force appeared to be defect free and a overall good weld; that is no worm holes, good interface bonding. However when the steel cover plate was removed, we noticed cracks between the nugget and parent-material interface in the 3000 and 2700 lbs forge welds. While looking at the microstructures it is evident there is a poor parent-material to nugget interface.

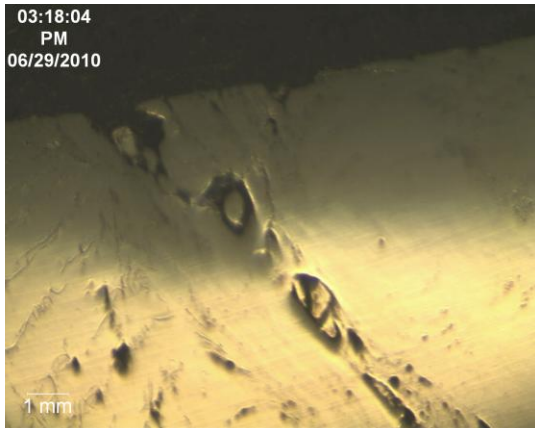

Fig. 5: Parent material and nugget interface.

When the steel cover plate was milled off the 3300 lbs force weld, there was no defect and the weld appeared good. However, there were problems which are discussed in the tensile test section under the Discussion section.

The welds also showed how the graphite flakes in the center of the nugget are extremely fine while in the parent material they are still long and relatively large.

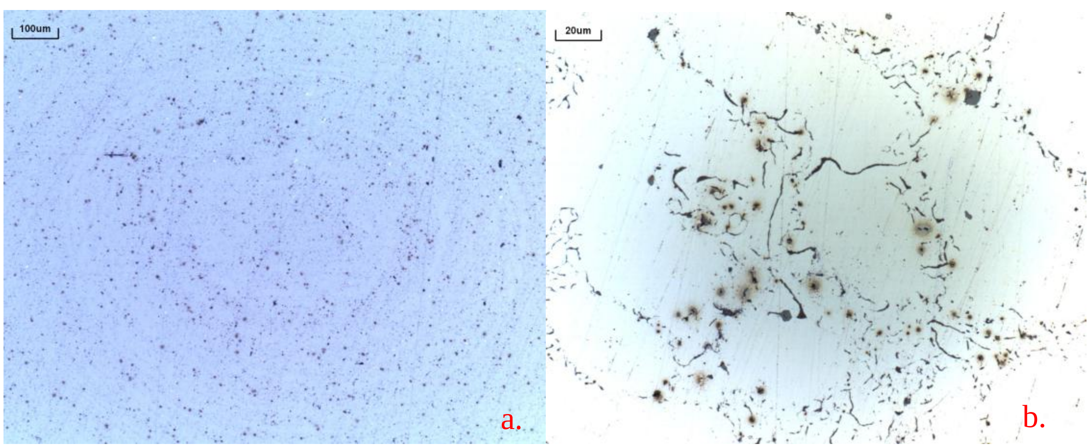

Fig. 6: graphite flakes in (a) center of weld and (b) parent material.

Tensile Tests

The tensile tests of the parent material gave results to those looked up for grade 40 grey cast iron. (2) all three of the tensile tests gave a modulus of approximately 15000 ksi. This data showed the machine was working correctly.

Due to a poor interface, only the 3300 lbs weld was able to be tested. The samples, however, were not as strong as we hoped. All tensile samples failed on the retreating side. Figure 5 shows the peak stress values of the FSW specimens compared to the parent material.

	Parent			FSW		Units
Peak stress	49.6	49.8	47.6	2.72	7.24	ksi
Percent elongation	1.27	0.98	1.08	0.823	0.49	in/in

Fig. 6: Tensile test results of parent material and FSW material.

The 3300 weld failed due to graphite segregation in the thermo-mechanically affected zone (TMAZ).

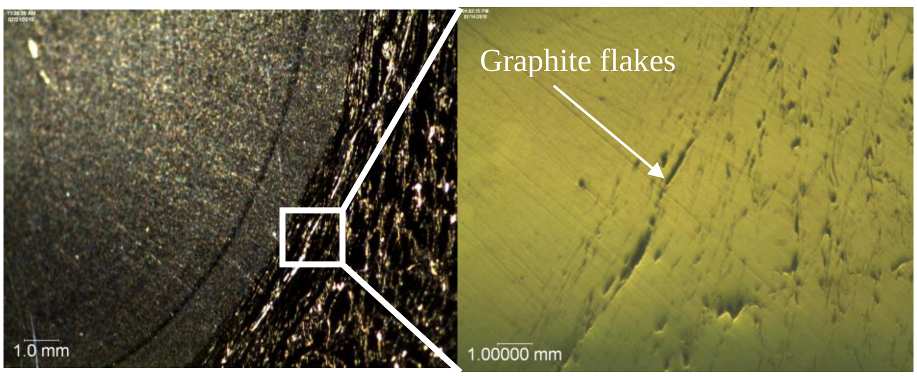

Fig. 7: Graphite segregation in TMAZ

A tensile sample made completely out of the nugget region of a 3200 lbf force weld was tested on the testing machine and proved to have a higher peak stress then either the parent or transverse FSW samples. In Fig 8 the peak stress and percent elongation can be seen.

		Parent		FSW		FSW nugget	Units
Peak stress	49.6	49.8	47.6	2.72	7.24	75.5	ksi
Percent elongation	1.27	0.98	1.08	0.823	0.49	0.49	in/in

Fig 8: Tensile test results of parent material, FSW cast iron, and FSW nugget samples.

From these results it is clear the nugget material is stronger than the parent material.

SEM and EDS

The SEM and EDS both showed a large amount of graphite on the fracture surface of the broken tensile samples.

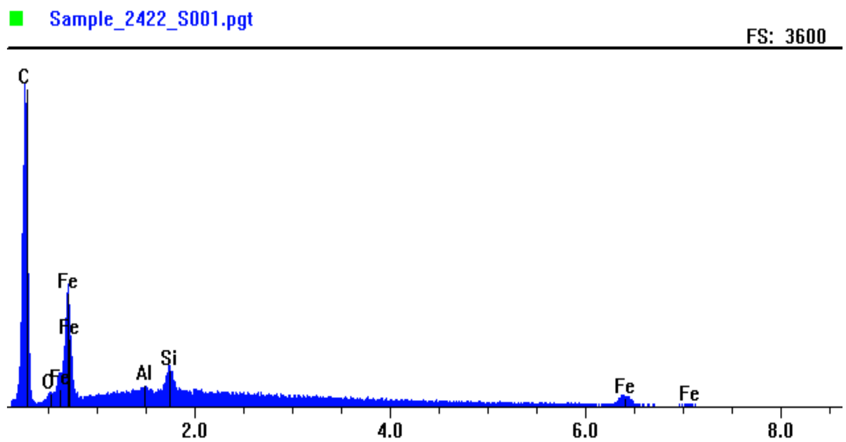

Fig. 9: Electron Dispersive Spectroscopy of broken tensile sample fracture surface

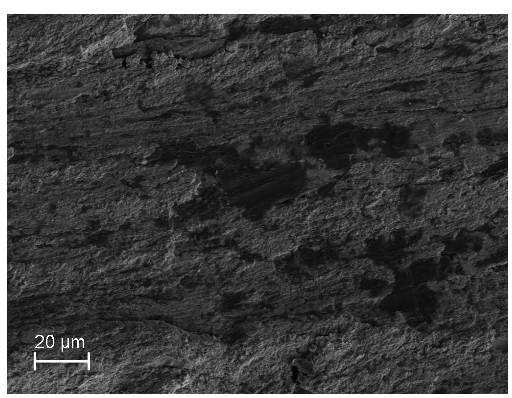

Fig. 10: Fracture surface covered in graphite flakes.

Figure 9 shows an EDS chart of the elemental makeup of the dark area located in the middle of figure 10. The amount of carbon shown in figure 9 suggests the black patches in figure 10 to be graphite flakes.

The EDS done within the nugget and on within the parent material did not show any significant differences in elemental composition.

Discussion

As stated previously, the 3000lbs and the 2700lbs were not able to be tested due to the poor interface between the parent material and nugget along the advancing side. The cracks in the 3000 lbs weld made breaking these samples fairly easy and some even did so with a slight push of the finger. When the steel cover plate was removed on the 2700 lbs a crack was underneath and it was discussed it was better not to do them, because of the poor quality of the 3000lbs weld.

While welding it became evident the material needed to be clamped in a specific way.

Fig. 11: Cast iron welds with different clamping methods

In the above figures the welds done using figures 11b and 11c were unsuccessful. The steel cover plate would bow continuously during the welding. We decided to look at previous welds and see how the issue was solved. Instead of having a steel cover plate to cover the entire material, a smaller cover plate was used and both the steel and cast iron plates were clamped simultaneously.

Conclusion

Even though FSW is a more effective way in welding grey cast iron, with the parameters we have used the results have not been up to those expected. The cast iron broke too easily and exhibited unwanted defects. Welds should be made with forge forces upwards of 3200 lbf.

Because of the use of the steel cover plate on the welds no weld dislodging has taken place. The steel cover plate allowed enough frictional heat to consolidate the graphite flakes in order to properly weld the cast iron. However, in order to keep the steel cover plates from bowing they need to be clamped a specific way, stated previously.

Future work includes the use of multiple welds with a constant 3300 lbf forge force weld in order to remove the retreating side of the weld all together. This will be accomplished by overlaying one weld 50% on the other weld. This should eliminate the graphite segregation which went on within the TMAZ on the retreating side.

References

[1]ASTM Standards E8, 2003, "Standard Test Method for Tension Testing of Metallic Materials," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/E0008_E0008M-09, www.astm.org.

[2] Gray Cast Iron. *Matweb*. Retrieved (2010, June 16) from http://www.matweb.com/search/DataSheet.aspx?MatGUID=ec56a89f37f74e2f867a64b0f87f1e9d&ckck=1

[3] Jasthi, Bharat, & Smith, Nick. (November 01, 2008) *CFSP08-AMP-01: Friction Stir Welding of Gray Cast Iron Annual Report*. Retrieved from AMP records.

[4] Pouranvari, M. (2010). On the weldability of grey cast iron using nickel based filler metal. *Materials and Design*, *31 (7)*, 3253-3258.

[5] Ramasubramanian, U. (2005). *Increasing the wear resistance of ASTM A48 grey cast iron by friction stir processing TiB_2 into the surface of the material* (Master's thesis). South Dakota School of Mines and Technology, Rapid City, SD.

.

Acknowledgements

This research was supported by a grant from the National Science Foundation. Special thanks to Dr. Michael West and Dr. Bharat Jasthi, Professor of English Dr. Alfred Boysen, and graphic art designer Melinda Poyourow. Thanks to Cummins for supplying the cast iron. Thank you to all SDSM&T faculty and staff for their contributions, support and assistance.