FRACTURE ANALYSIS OF A 1994-1997 HONDA EXHAUST MANIFOLD

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ABSTRACT

The purpose of this investigation was to discuss the reasons for the fracture in the 1994-1997 Honda Accord exhaust manifold and to suggest solutions to prevent future failures. This team was assigned to determine the root cause for the failure of this auto part and establish a solution to prevent similar fractures from happening in the future. The exhaust manifold examined was made from a gray cast iron that was sand casted. Examination methods used included stereo microscopy, metallography, and scanning electron microscope (SEM). The stereo microscope and the SEM images show that this is a ductile brittle fracture, while metallography revealed that there were graphite nodules around the site of the fracture. From this data, it was determined that the root cause for the exhaust manifold fracture is due to poor inoculation before sand casting. To prevent future failed exhaust manifold parts, regulating the process of inoculation should be implemented to prevent the growth of nodules in the microstructure.

INTRODUCTION

Exhaust manifolds extract gases from the combustion chamber of an engine, and join the exhaust from each cylinder into a single pipe to be run through the catalytic converter and out the back of the car. Since the exhaust gases at the manifold are taken out of the cylinders immediately after combustion, the manifold is subjected to operating temperatures of around 1000℉. Exhaust manifolds are generally cast parts that have been designed to dampen vibrations and undergo a high thermal gradient, which makes the part expand and contract [1]. The expansion and contraction cycles are designed for this, but over longer periods of time, the manifolds are expected to fail after five to six years of use.

PROCEDURE

Procedure steps:

Optical Examination

The first step done after the manifold was received was visual examination. The part was received already cut into 5 pieces, so the part was reassembled to determine the location of the crack relative to how the part was mounted (Figure 1). Each part section was labelled with a letter designation for convenience (Figure 2).

Figure 1: Configuration of how the exhaust manifold should look when all the unattached pieces are reconnected.

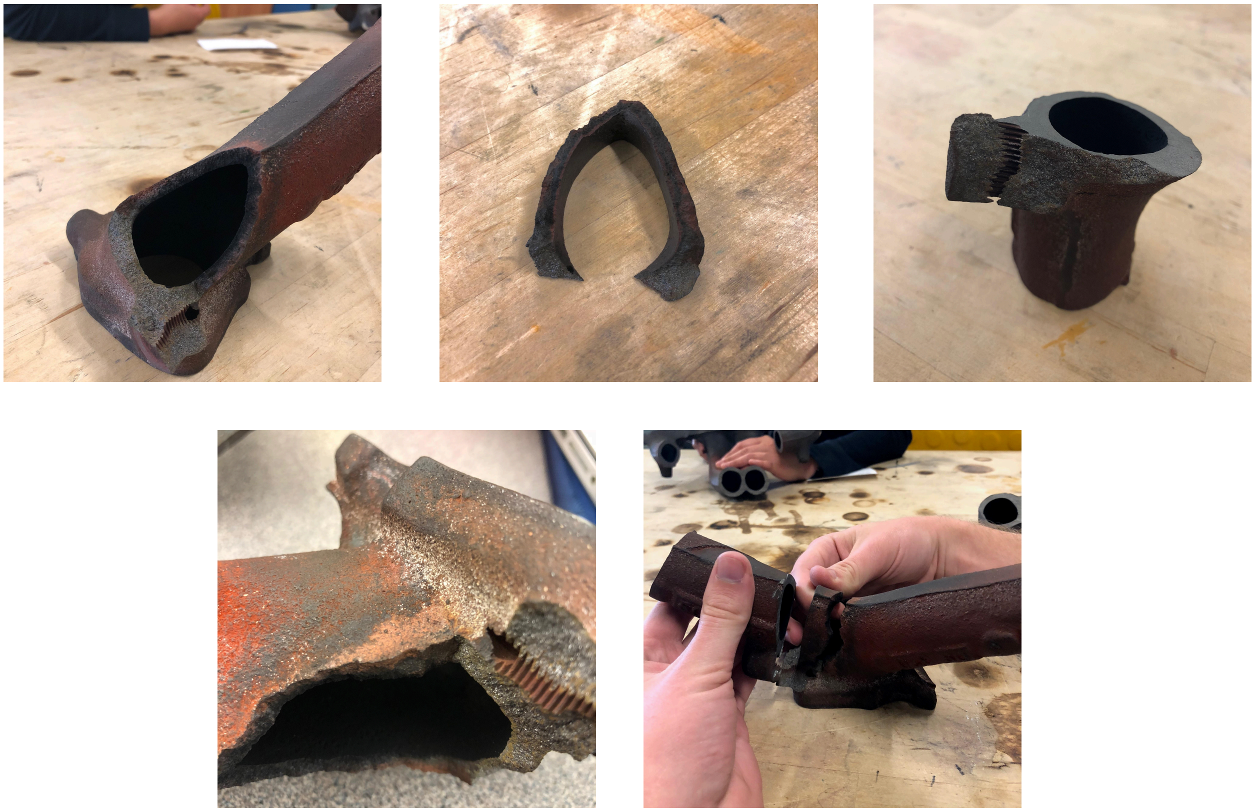

Figure 2: Dismembered pieces of the exhaust manifold given for analysis. (a) and (b) are

After reconstruction, the parts were examined separately to determine how many parts had experienced failure. Each part was photographed and catalogued. Part photos were taken using an iPhone 8 camera. Following the visual examination, a Leica MZ6 stereoscope was used to examine the fracture surfaces of the part b. Examinations were carried at 6.3x magnification on pieces X and Y.

Metallography

For examination of the manifold's composition, a section of the exhaust manifold was removed using an abrasive cutoff wheel. Due to the geometry of the part, the section was taken away from the fracture surface as it was the only way to ensure a clean cut. The section was not mounted in bakelite because of its size. The cut side was polished to a mirror finish, and a Leica DR IRM was used to take bright fi images before etching. Images were taken at 50x, 100x, 200x, and 500x along the outside edge, inside edge, and mold seam. Once imaging was done, the sample was etched with 2% nital, cleaned with ethanol, and imaged again at the same magnifications.

Scanning Electron Microscopy

A FEI Quanta 200 scanning electron microscope was used to take images of the fracture surface up close. Images were taken using high vacuum at 15 kV. The spot size used was 4 nm to ensure high resolution images. Images were taken of the ferrite-carbide fracture surface at magnifications between 100x and 5000x.

Results

2.2. Stereo Microscopy

Stereo microscopy revealed a dull gray fracture surface, with some smaller cracks visible running perpendicular to the outer and inner surfaces of the casting. There was also contamination visible on sections towards the top of the “horseshoe” shaped sample (Figure 3). These contaminated areas indicated the crack growth over time, since the partially cracked sections were subjected to vibrations causing them to rub together, as well as exhaust flow escaping through the crack, contaminating and wearing down the surface. The final fracture is clearly visible as the dull gray area of the fracture surface.

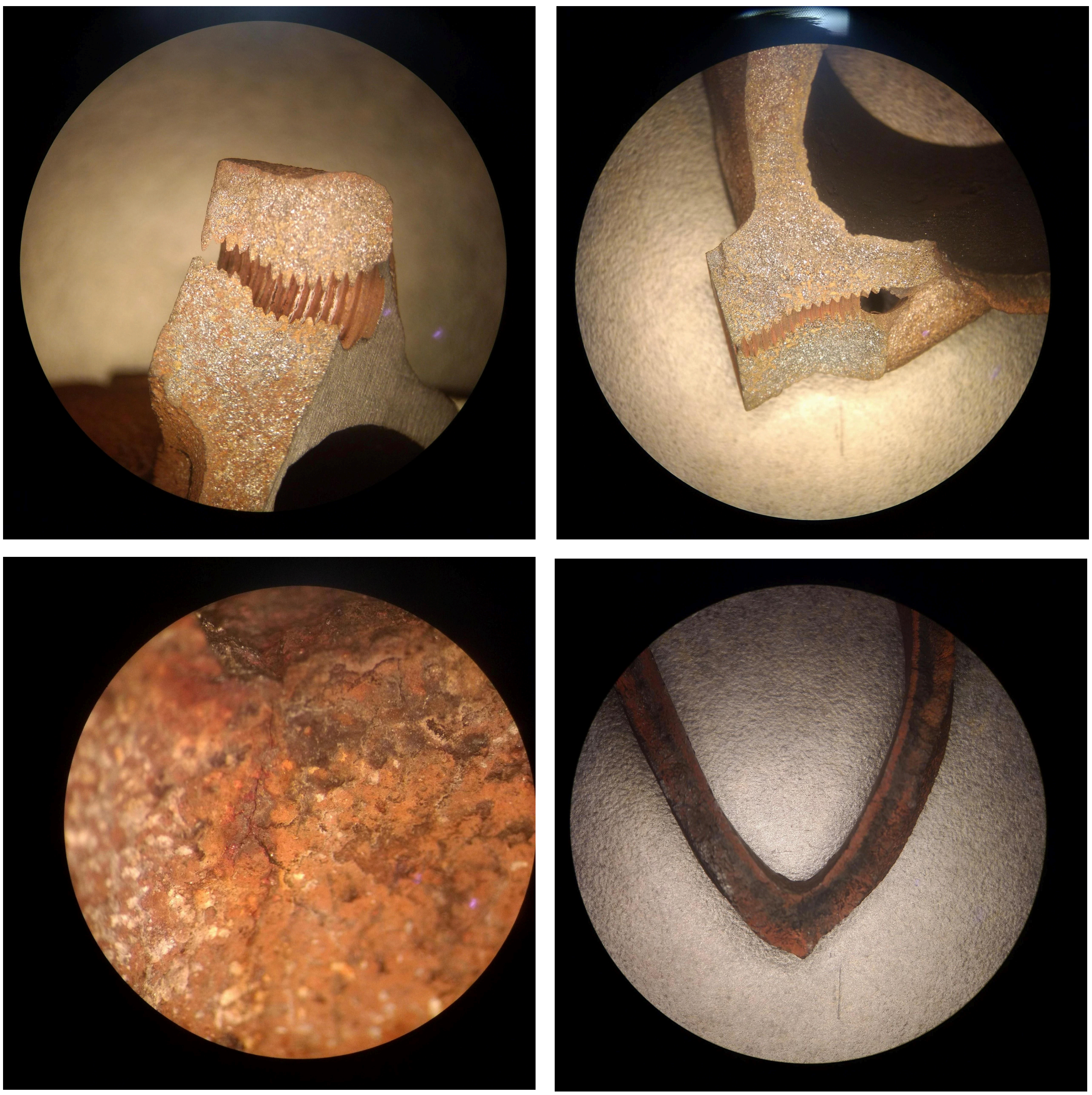

Figure 3: Stereo microscopy of different fracture surfaces

2.3. Metallography and SEM Sample Preparation

Metallography

Metallography of a typical section of the manifold near the fracture was performed to evaluate the microstructure and inclusions in the metal. Grinding and polishing revealed a characteristic cast iron microstructure, with large graphite flakes clearly visible throughout the sample (Figure 4). Etching was performed to further reveal the microstructure, primarily inclusions or other particles. Etching revealed the presence of nodules in the sample, which can be clearly seen in Figure 5. These nodules and voids are intermixed with and surrounded by the graphite flakes that were visible before etching.

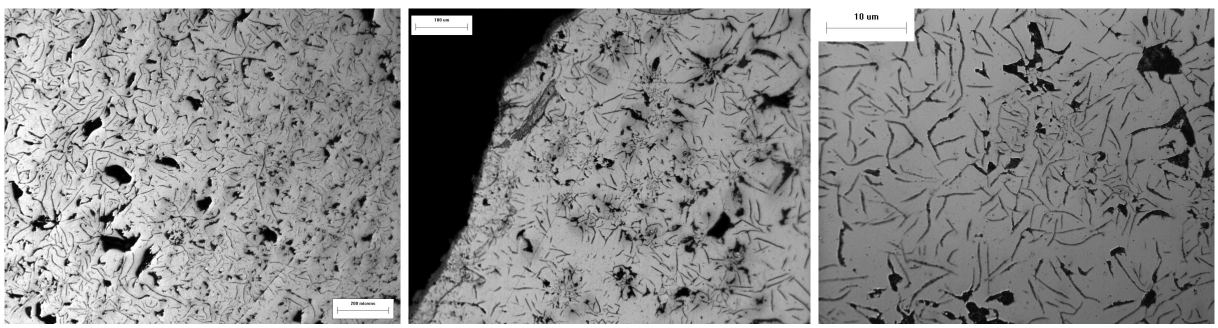

Figure 4: Images of polished and unetched sample. (a) shows the base metal at 50x magnification, (b) shows the inside edge at 100x magnification, and (c) shows the inside edge at 200x magnification.

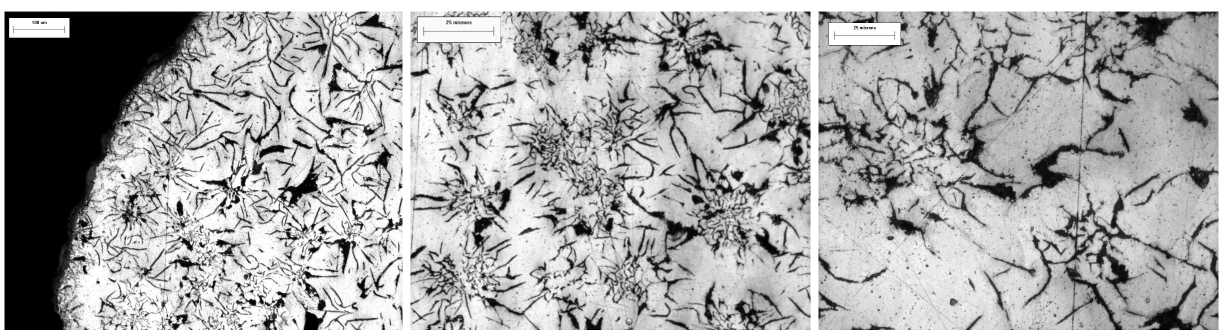

Figure 5: Images of polished and etched sample. (a) shows the inside edge at 100x magnification, (b) show the inside edge at 200x magnification, (c) show the inside edge at 500x magnification.

2.4 Scanning Electron Microscopy (SEM)

SEM imaging revealed two primary fracture surfaces. The first fracture surface is the undisturbed fracture surface, which was also characterized as a “flakey” fracture surface (Figure 6). This is because the fracture surface clearly shows the graphite flakes which were observed during metallography. Due to the fine appearance of this surface, it is most likely an untouched surface.

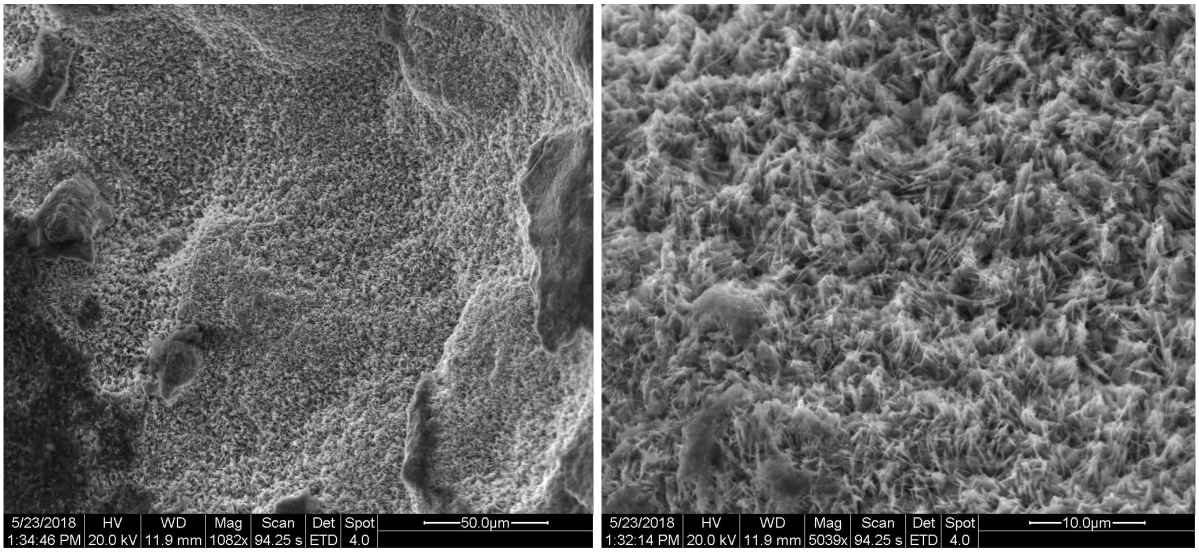

Figure 6: Typical undisturbed fracture surface displaying exposed graphite flakes.

The second observed fracture surface is a typically smooth surface. This surface is formed by erosion from the flow of exhaust gases and vibrations rubbing the crack surfaces together while the part was still intact (Figure 7). This smooth surface is typically found in raised areas where the exposure to exhaust gases and other surfaces was the highest. Figure 8 shows a close up of a transition between the two surfaces, with one image being focused on the flakey fracture surface, and the other being focused on the raised smooth section.

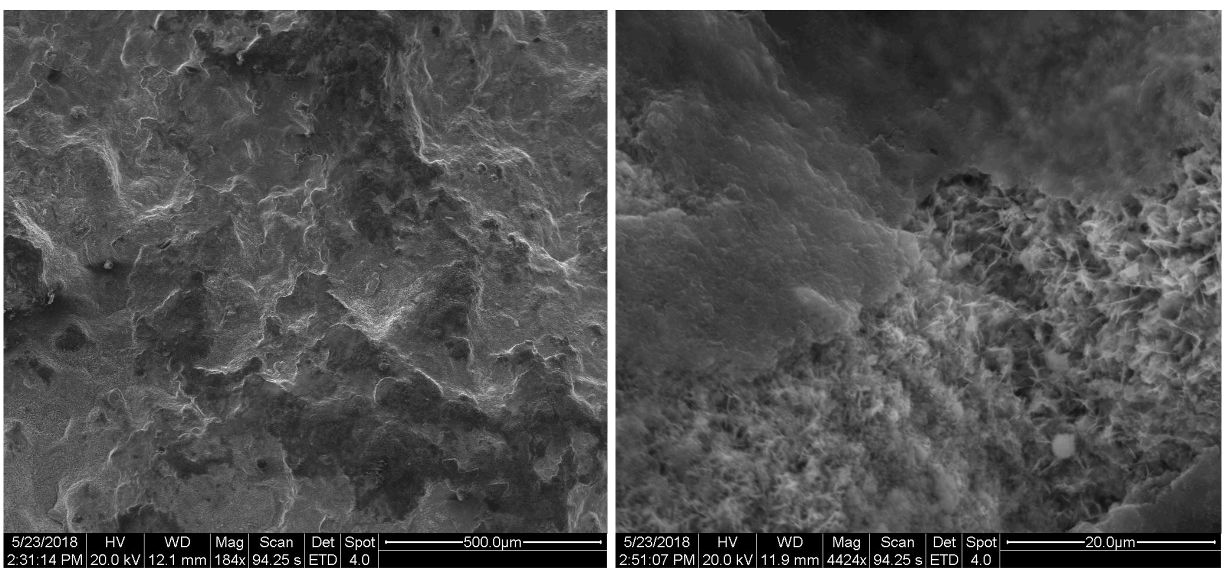

Figure 7: Worn fracture surface shown on the left. Right image shows combination of worn and flakey fracture surfaces.

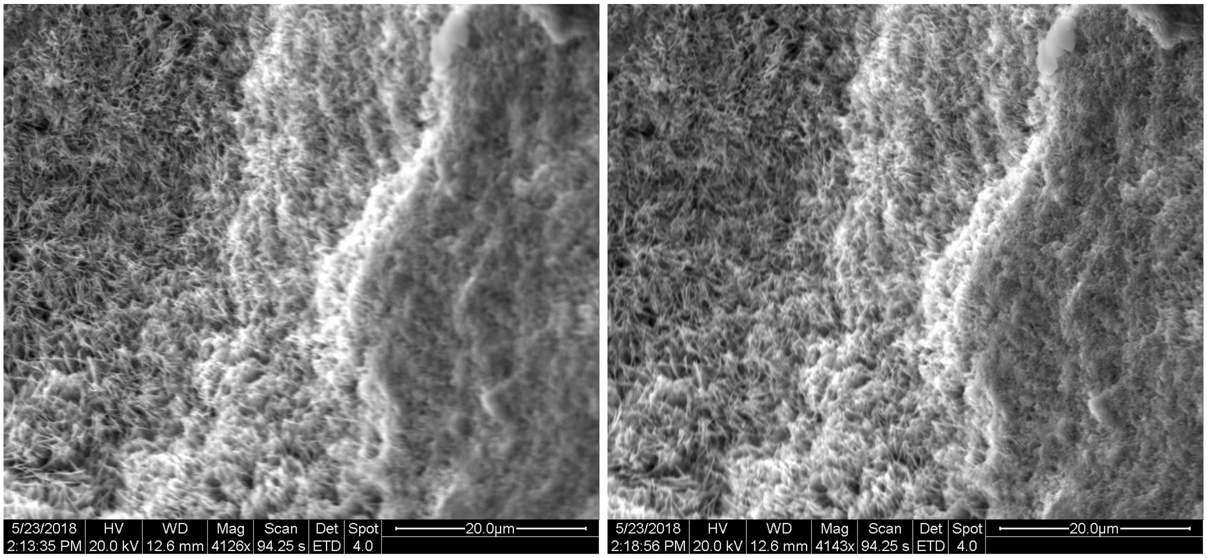

Figure 8: Contrast of two fracture surfaces found near the tip of the casting. The image on the left is focused on the lower region typical of an undisturbed or flakey fracture. The image on the left is focused on the raised region which has been eroded by exhaust flow and vibrations.

DISCUSSION

Exhaust manifolds are subject to extreme conditions, which can lead to failures if not fully considered. The primary mechanism of damaging the manifolds comes from the extreme thermal cycling they experience. These temperatures range from ambient to 1000℉, and up to 1200℉ in extreme applications [2]. The manifold can experience these temperature swings four or more times a day, depending on how often the vehicle is being driven. This cyclic loading fatigues the material, affecting it the most in areas prone to failure such as those with stress concentrating geometry or other loads being applied [3].

Vibrations are also a factor in the deterioration of the manifolds. As the engine operates, it is constantly vibrating with the engine; this vibration will propagate existing cracks or flaws in the manifold, which can contribute to part failure along with existing stresses [4]. While there are typically spring mounted or rubber mounted components in the rest of the exhaust system to dampen vibrations, the Honda Accord application evaluated does not appear to have any system of isolating the manifold from vibrations. The lower section of the manifold bolts to the catalytic converter, as well as the engine block via a bracket. The lack of insulation from vibration most likely contributed to opening up the crack over time, causing the eventual catastrophic failure of the part.

These manifolds are usually casted as seen by the microstructures seen in Figures 4 and 5. These result in the typical cast iron microstructure with graphite flakes which form during solidification in an austenite matrix (Figure 9). Silicon is alloyed to promote graphite formation to yield low ductility, moderate strength, and high thermal conductivity. The wear and abrasion resistance of gray cast irons usually depend on the microstructures.

Figure 9: The preferred graphite flake structures for gray cast iron.

Depending on the conditions during solidification, the graphite morphology and distribution may vary. In the case of the manifold, the microstructures revealed Type B morphology (Figure 10).

Figure 10: Type B graphite morphology. This structure is the most similar to the structures seen in the manifold.

According to ISO 945, Type B morphology is due to poor inoculation. Inoculating the molten steel prior to casting introduces sites for eutectic graphite to nucleate as flakes during solidification. The precipitation of SiO_2 nuclei occurs during inoculation, which are sites for the graphite to grow. Effective inoculation results in uniform mechanical material properties and the prevention of the formation of iron carbide [5]. When the steel is poorly inoculated, there are not enough nucleation sites for the graphite flakes to distribute, producing an inhomogeneous graphite flake structure. This nonuniformity in the distribution of the flakes can be seen in the SEM images, causing localized areas of carbide formation.

CONCLUSIONS

1. Poor inoculation led to carbides concentrating at the mold seam.
2. Flaws in the microstructure led to a crack forming on the outside of the manifold.
3. Vibrations during normal use opened up the crack further, until eventually the crack propagated all the way through the part and failure occurred.

RECOMMENDATIONS

1. The quality of the casting should be more tightly regulated, to prevent poor microstructures associated with poor inoculation. This should reduce the flaws which cracks can start at, and therefore increase the toughness of the manifold and increase its service life.
2. The mounting for the manifold should be revised to include a system for dampening the vibrations, such as a spring or rubber mount. The current system is hard mounted on both sides, increasing the sensitivity to vibrations. With a damped mounting system, the manifold should be less sensitive to vibrations propagating any cracks.

REFERENCES

[1] Maschke, W. (n.d.). *Metallurgy Overview* [PDF]. Hilden, Germany: Ask Chemicals. http://www.ask-chemicals.com/fileadmin/user_upload/Download_page/Foundry_Products_Brochures/EN/Metallurgy_Overview_EN.pdf

[2] Surface Temperature: Underhood. (n.d.). Retrieved June 8, 2018. http://depts.washington.edu/vehfire/ignition/autoignition/surftemper.html

[3] Johnston, V. (2015, November 25). What Causes an Exhaust Manifold to Crack or Leak? Retrieved June 4, 2018. https://www.yourmechanic.com/article/what-causes-an-exhaust-manifold-to-crack-or-leak

[4] *Application and Installation Guide: Exhaust Systems* [PDF]. (2013). Caterpillar. http://s7d2.scene7.com/is/content/Caterpillar/CM20160713-53120-15686

[5] Maschke, W., & Jonuleit, M. (n.d.). *Inoculation of Cast Iron* [PDF]. Dublin, OH: Ask Chemicals. http://www.ask-chemicals.com/fileadmin/user_upload/imagery_docs/press/Professional_Articles/EN/Inoculation_of_cast_iron.pdf