

Nondestructive Evaluation: Correlation of Selectively Leached Thickness to Hardness for Gray Cast Iron and Brass

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EPRI Project Manager

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ABSTRACT

This report addresses the one-time inspection requirement for license renewal involving the selective leaching of gray cast iron and brass components in nuclear power plants.

Within the one-time inspection program established to address license renewal, the operating utilities are required to inspect components made of gray cast iron and copper alloys that are susceptible to selective leaching and de-alloying. Visual inspection and hardness measurement are employed, where applicable, to meet the inspection requirements. In the recent Generic Aging Lessons Learned (GALL) report, the acceptance criterion for hardness was given as less than 20% decrease in hardness.

This report documents an effort to correlate hardness values to selectively leached thickness of gray cast iron and brass components. This was accomplished by using a set of gray cast iron and brass samples. First, the samples were artificially leached in a controlled environment. Next, the selectively leached thickness values were measured along with the associated hardness values, for each of the tested specimens. Finally, a correlation curve between hardness and selectively leached thickness was attempted to show this relationship.

This report provides results of the attempted correlation between hardness and selectively leached thickness of the samples made of gray cast iron and brass.

Keywords

Gray cast iron

Brass

Selective leaching

Hardness

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INTRODUCTION

Selective leaching of metal alloys is a form of corrosion in which one of alloying elements is dissolved or leached, resulting in a decrease in material strength and hardness. Since this corrosion process occurs very slowly, as a part of one-time inspection program for license renewal utilities often perform visual inspection and hardness testing.

To obtain more quantifiable information, alternative nondestructive evaluation (NDE) methods were introduced initially by the Electric Power Research Institute (EPRI) as complements to visual and hardness testing. This involved applications of the Ferroscope NDE system and phased array ultrasonic procedure for components made of gray cast iron materials that were susceptible to graphitic corrosion [1]. Another effort involved eddy current evaluation of de-alloyed heat exchanger tubing made of Admiralty brass [2].

No industry-wide acceptance/rejection criteria were available prior to 2010, because it was difficult to establish any definitive damage growth rate for those components since they were being inspected for the first time. The susceptible components included in the one-time inspection program were replaced in most cases if they were found to exhibit graphitic corrosion or de-alloying.

In December of 2010, Revision 2 of the Generic Aging Lessons Learned (GALL) Report, NUREG-1801, Rev. 2, was published. In the report, the acceptance criterion for hardness testing was given as less than 20% decrease in hardness value. This resulted in this year's project objective of establishing a correlation curve between hardness and selectively leached thickness. Based on the established correlation curve, a given thickness associated with a 20% reduction in hardness can be measured and quantified in the field to determine its acceptance/rejection status.

For this project, a chemical dissolution method at an elevated temperature was used to accelerate and artificially leach a set of controlled specimens made respectively of either gray cast iron or brass.

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EXPERIMENTAL PROCEDURES

Two kinds of test materials were used in this investigation. One was a gray cast iron specified as KS D-4301 GC250 (tensile strength $> 250 \text{ N/mm}^2$), which is similar to ASTM A48. The other was a brass specified as UNS C26000 that consists of 70% copper and 30% zinc, which is similar to ASTM B-135 C26000. These test materials were fabricated as hexahedron specimens with a 1-inch \times 1-inch (25.4-mm \times 25.4-mm) cross-sectional area and a thickness of 0.5 in. (12.7 mm). The specimens were set in a block of epoxy resin, and the upper surface of the block was mechanically polished with a 2000-grid silicon carbide paper to a given surface finish. Some of the fabricated brass specimens are shown in Figure 2-1.

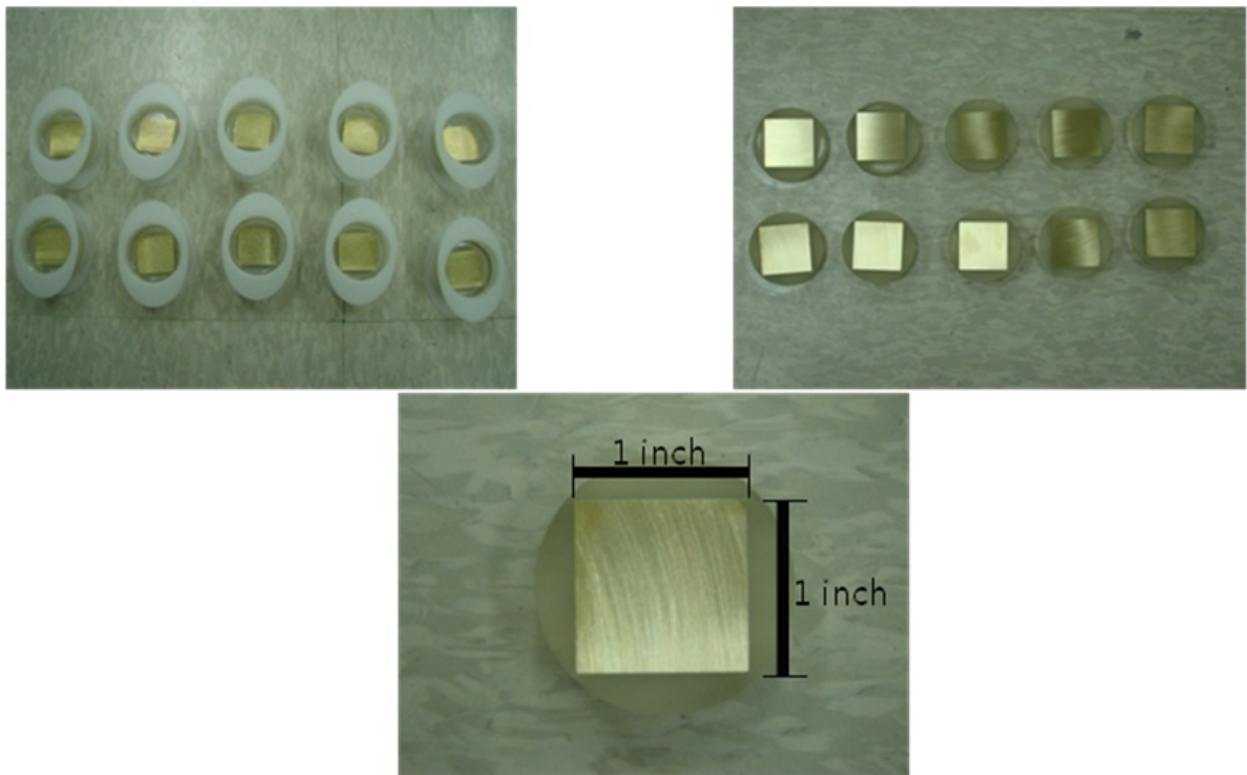


Figure 2-1
Fabricated Brass Specimens, Showing Surface Finish and Sample Dimensions

The leaching solution for gray cast iron was prepared by dissolving 2.5 gram (g) of iron sulfide (FeS), 25 g of sodium sulfate (Na_2SO_4), and 25 milliliter (mL) of hydrochloric acid (HCl) with 30% weight concentration in 500 mL of water at 167°F (75°C). For brass, 6.34 g of cupric chloride ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$) was added to 500 mL of water at 167°F (75°C).

Each tested specimen was dipped into the hot solution bath and the selectively leached layer was controlled by changing immersion bath time. The hardness measurement was performed in Brinell scale using the portable Equotip hardness tester shown in Figure 2-2.



Figure 2-2
Equotip Portable Hardness Tester Used for Brinell Hardness Testing

After the hardness measurement, the specimen was cut into halves and polished with a 3- μm -diameter diamond paste to measure the selectively leached thickness with an optical microscope.

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RESULTS AND DISCUSSION

Gray Cast Iron

Figure 3-1 presents the optical micrographs showing the cross-sectional views of selectively leached gray cast iron samples. During the selective leaching process, iron dissolved away from gray cast iron, leaving only the graphite matrix. However, since graphite is soft, the graphite matrix detached easily from the resin surface. As a result, air pockets were observed at some locations within the selectively leached layer, as shown in the figure. It was also noted that the selectively leached layer increased with increasing immersion time in the leaching solution at an elevated temperature of 167°F (75°C).

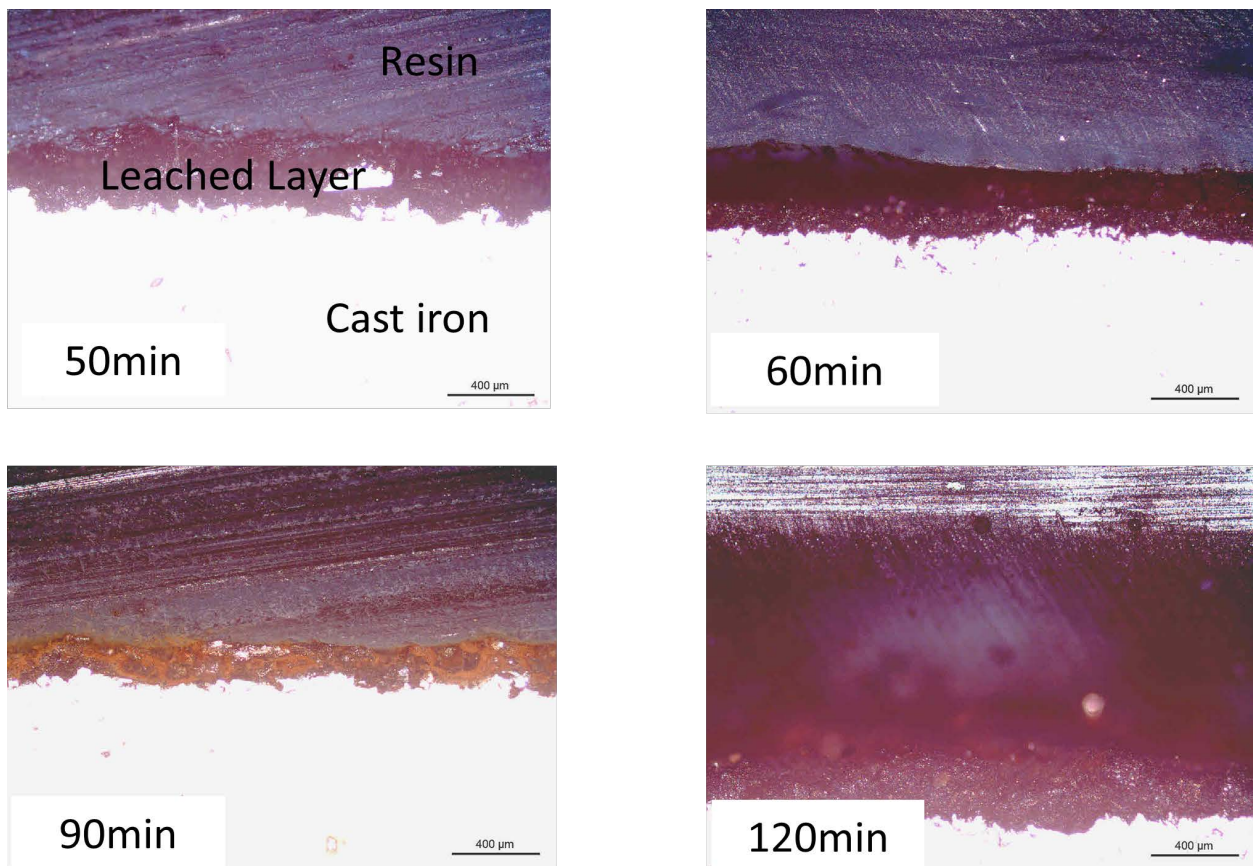


Figure 3-1
Selectively Leached Gray Cast Iron Samples, by Exposure Time at 167°F (75°C)

Figure 3-2 depicts the relation between hardness and the selectively leached thickness for gray cast iron. It should be noted that hardness values were obtained after taking seven measurements from a given sample by averaging the five middle values while excluding the maximum and

minimum hardness values. To obtain the 20% decrease in hardness, the original baseline hardness value was obtained first from the prepared sample before it was immersed in a chemical bath.

From the figure, it was noted that the hardness of gray cast iron dropped drastically to values below 80% of the initial hardness values. This drop equated to a selectively leached layer thickness value of around 250 μm . Furthermore, it was noted that hardness values could not be obtained for gray cast iron specimens if they were immersed and selectively leached for 240 minutes. This implies that hardness value may not be an appropriate parameter to associate with the selectively leached thickness of gray cast iron. Even from those selectively leached samples exposed to the chemical bath for less than 50 minutes, low hardness values were obtained. Therefore, no meaningful correlation was established between hardness and selectively leached thickness of gray cast iron.

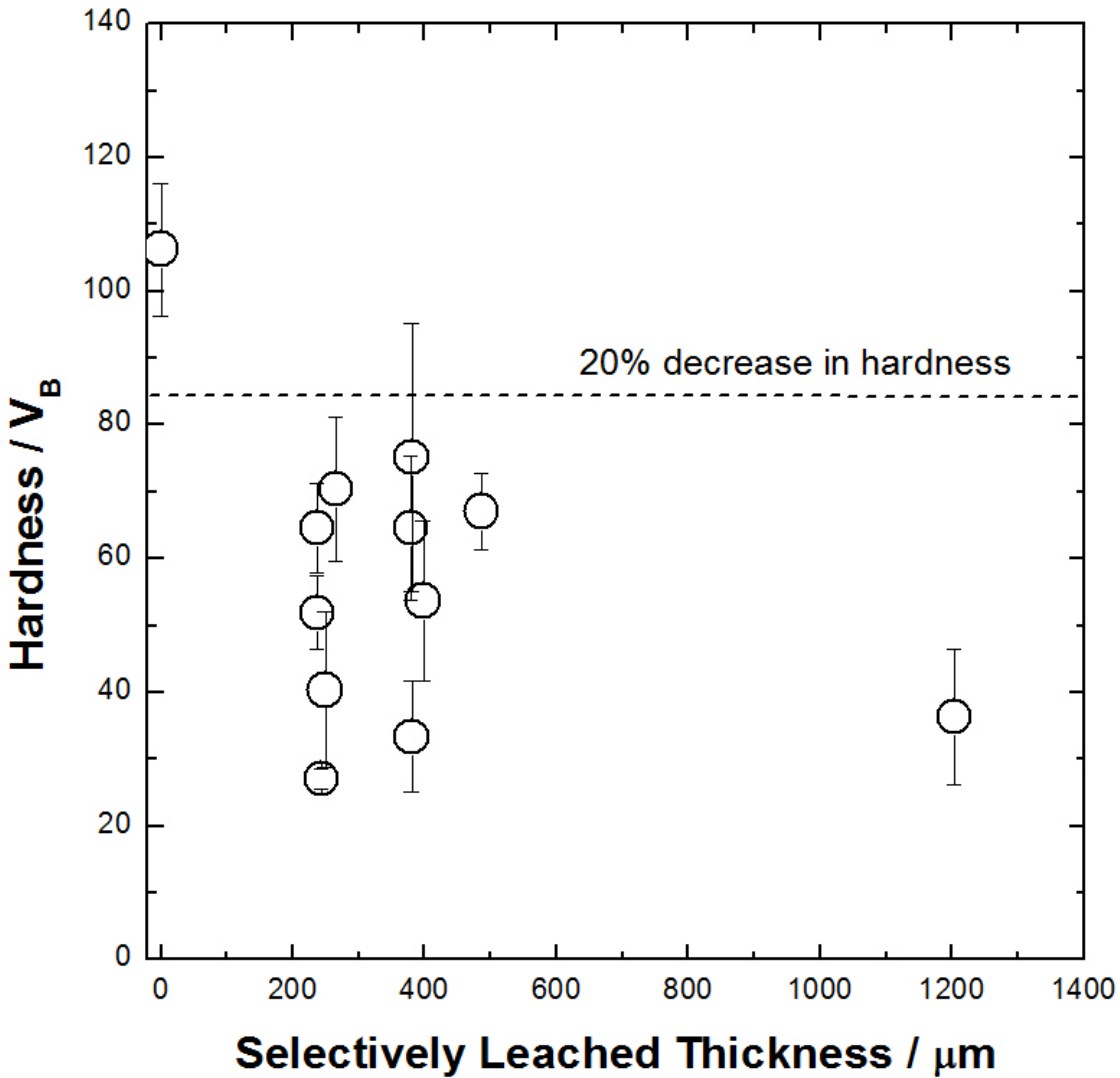


Figure 3-2
Relation Between Hardness and Selectively Leached Thickness for Gray Cast Iron

Brass

Optical micrographs of brass after selective leaching are shown in Figure 3-3. Unlike with the gray cast iron, the selectively leached layer remained on the surface. The figure also shows that the de-alloyed thickness increased with increasing immersion time.

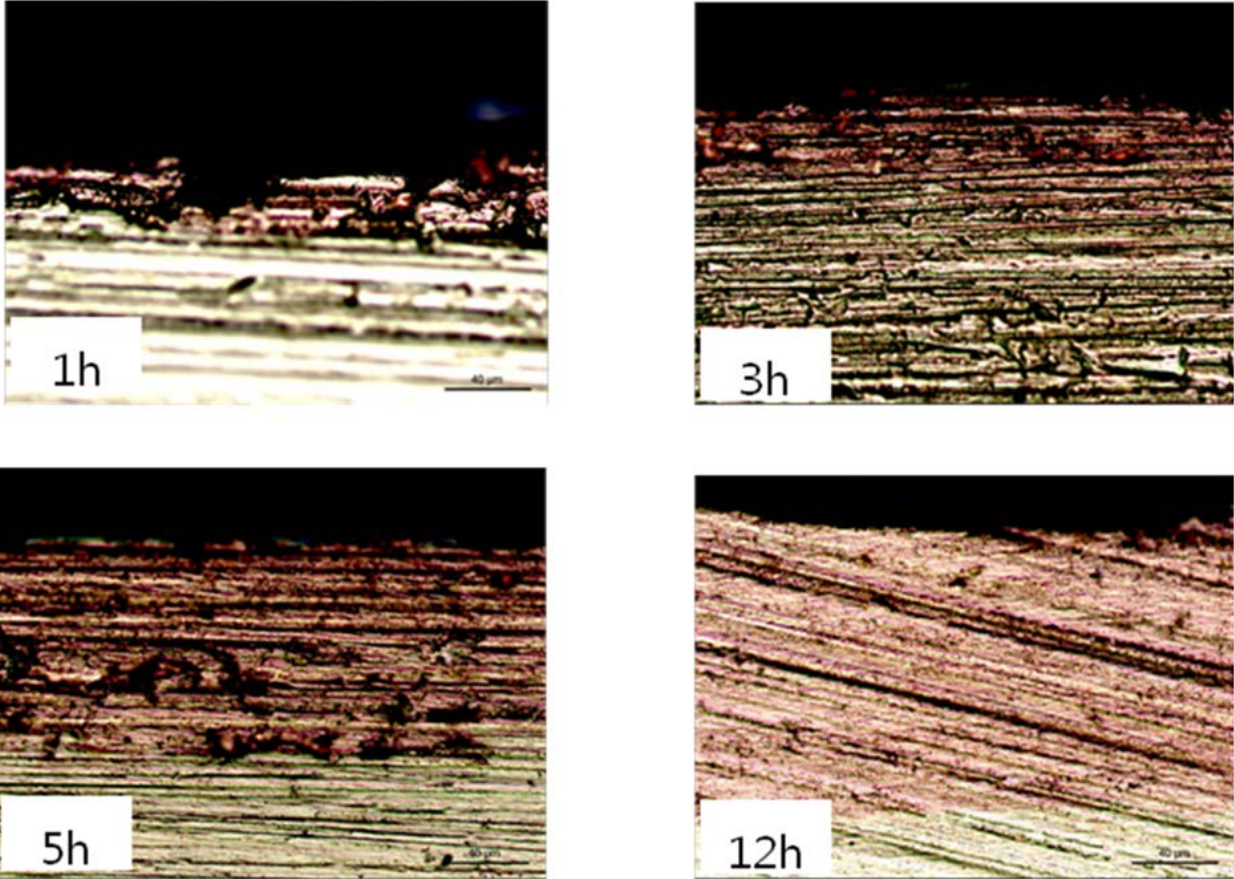


Figure 3-3
Cross-Sectional Optical Micrographs of Selectively Leached Brass Samples, Showing Increased De-Alloyed Thickness with Increased Immersion Time

Figure 3-4 shows the linear regression between hardness and selectively leached thickness for brass. The correlation shows that, on average, hardness drops below 80% of its initial value when the selectively leached layer thickness reaches 97.9 μm .

As with gray cast iron, the results imply that any observation of de-alloying would likely exceed the hardness acceptance criteria.

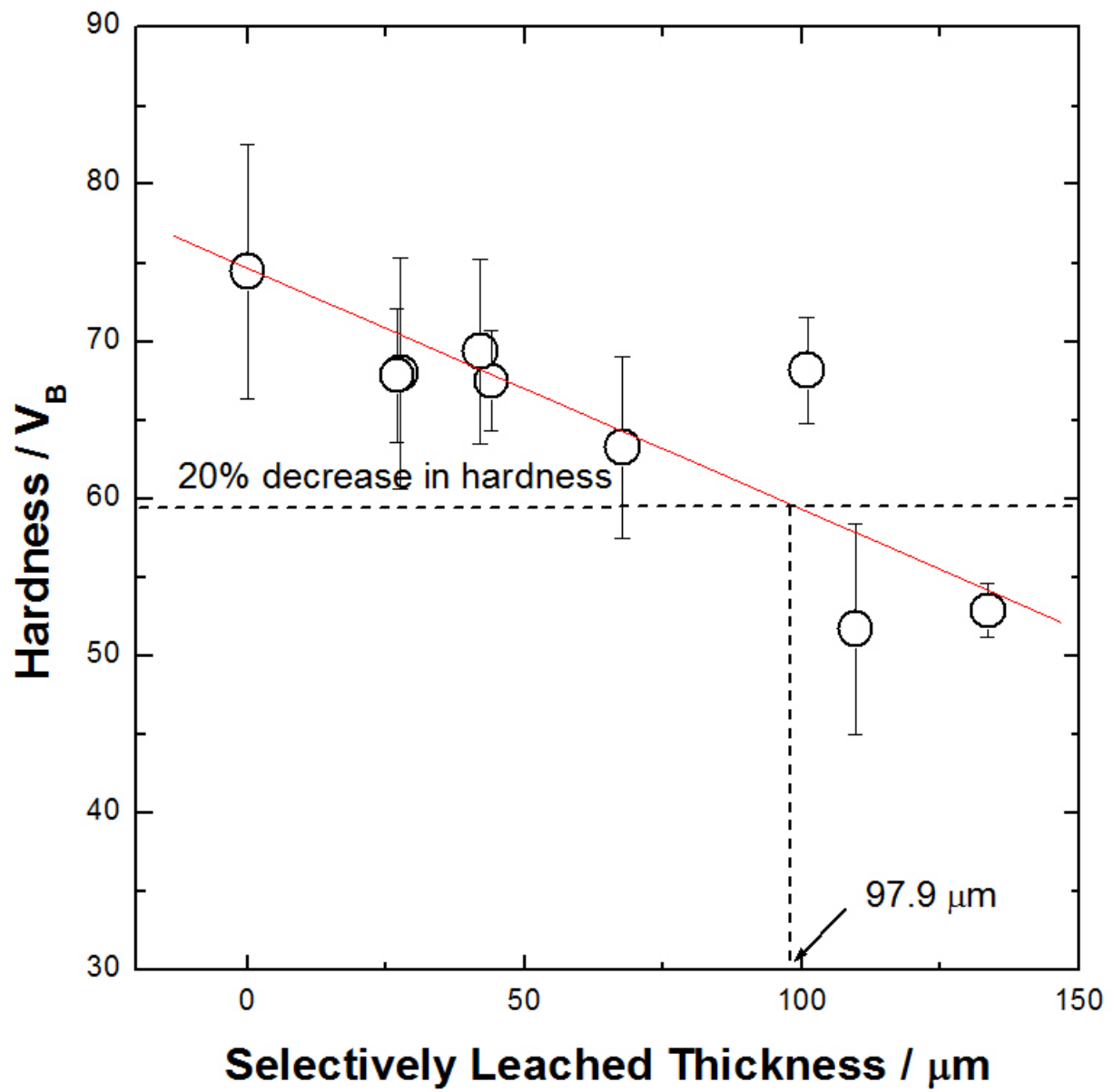


Figure 3-4
Relation Between Hardness and Selectively Leached Thickness for Brass

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SUMMARY AND OBSERVATIONS

The following summary and observations are noted based on the project work:

- A correlation between decreased hardness and increased thickness after selective leaching was established for brass.
- A correlation between decreased hardness and increased thickness after selective leaching could not be established for gray cast iron due to the soft carbon matrix falling off of the prepared samples.
- For both materials, hardness values dropped below the GALL acceptance criterion once the selectively leached layer thickness exceeded 200 μm for gray cast iron and 100 μm for brass.
- The 20% drop in hardness value criteria was found to be very conservative, resulting in repair/replacement of affected components when the selective leaching damage form is identified.
- Based on the above observations, it is prudent to continue with the industry practice of performing visual testing and cutting samples when possible to confirm presence of selective leaching. Depending on the estimates of growth rate, continue to monitor or perform repair and replacement of affected components with either same or more corrosion-resistant materials.

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REFERENCES

1. *Nondestructive Evaluation: Update to NDE for Selective Leaching of Gray Cast Iron Components*. EPRI, Palo Alto, CA: 2009. 1019111.
2. *Nondestructive Evaluation: Plant Aging/License Renewal Nondestructive Examination Gap Solutions and Strategies – Volume 3*. EPRI, Palo Alto, CA: 2010. 1021162.

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