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# FEASIBILITY OF SPECIAL TRACKWORK INSPECTION USING ULTRASONICS

## SUMMARY

The Federal Railroad Administration (FRA) co-sponsored Transportation Technology Center, Inc. (TTCI) on a trackwork inspection effort scheduled for completion in September 2022. This research demonstrated the potential for the low-frequency ultrasonic testing (UT) nondestructive evaluation (NDE) method to characterize internal flaws in crossing diamond samples with coarse grain structures.

First, TTCI fabricated a test sample from the crossing diamond that contained drilled holes (reflectors) at different depths. Second, microstructural analysis and microhardness measurements characterized its microstructural and material properties. And third, researchers applied a low-frequency UT method to detect the reflectors in the test sample.

## BACKGROUND

Most of the mainline frogs and crossing diamonds are made with austenitic manganese steel (AMS) castings. Although NDE approaches have been used routinely in the railroad and other industries for many decades, conventional high-frequency UT of AMS steel castings is difficult because the wave propagation medium in an AMS casting is highly attenuative in nature.

Railroads employ special trackwork, such as turnout frogs and crossing diamonds, at critical locations. Special trackwork primarily helps support and direct the railcar from one track to another or to cross intersecting tracks. The service lives of special trackwork are greatly affected by wheel loads and speeds of the trains that operate over them. Due to the higher dynamic loads generated by heavy axle load (HAL) service, increased stress, and shortened life cycles, diamonds and frogs are also frequently associated with train delays for slow orders and maintenance activities [1]. The areas of most wear and damage on the diamonds and frogs are mainly associated with the nose or point, and joints at the end of the castings. Figure 1 shows an example of a frog with surface damage near the nose/point region.

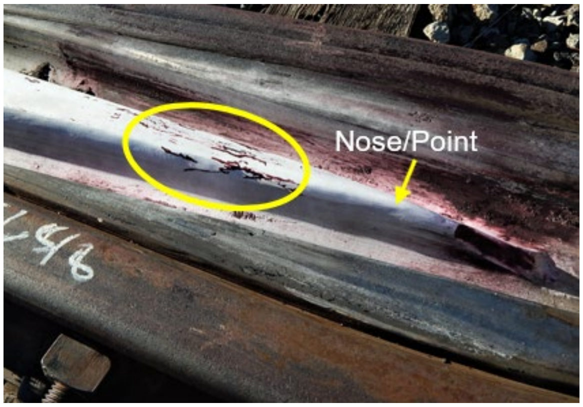

Figure 1. Example of a frog exhibiting surface damage

Special trackwork components are difficult to inspect due to the complex shapes involved (which varies with length), the composite construction (e.g., rail-bound frogs), and the material used (e.g., AMS casting). These special trackwork components can develop flaws (cracks) in different locations and at potentially different depths as tonnage and mileage accumulates during revenue service operation. The current best practice for repairing visual cracks in the AMS casting involves removing and grinding materials (i.e., U groove pattern) until the cracks disappear or to a predetermined depth of 0.5 inch (12.7 mm) or deeper. This is highly subjective and may not completely remove cracks or flaws.

## OBJECTIVES

TTCI studied the applicability of a low-frequency UT NDE approach for internal defect detection in special trackwork material. Manufacturers currently inspect crossing diamonds using the radiographic NDE method (i.e., used for fullvolumetric examinations of components prior to shipment). This method is time-consuming, costly, and requires special facilities and highly trained personnel. An alternative low-frequency UT NDE method would have many benefits, possibly including the ability to inspect crossing diamonds while in service. Revenue service examinations of these special trackwork components currently use only visual inspections. By the time a defect or flaw is visually detected, the structural integrity of the component may already be compromised, and immediate repair or replacement may be required.

## EXPERIMENTAL APPROACH

Figure 2 shows a spare new AMS crossing diamond casting TTCI used for this study.

Figure 2. Crossing diamond, yellow triangular wedge shape shows the cut made

A small piece was cut out to generate a wedge-shaped sample from this casting. Several through-holes were then drilled into this wedge-shaped test sample for the ultrasonic NDE study. Also, a small piece of the sample was cut out and analyzed for the microstructural analysis and micro-hardness measurement. Figure 3 shows the engineering drawing of the crossing diamond wedge sample with drilled through-holes of different diameters drilled at different depths from the surface of the sample.

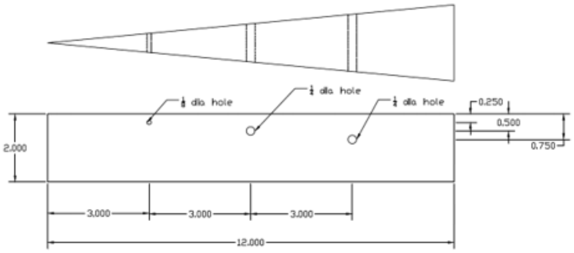

Figure 3. Top-view crossing diamond wedge sample with through-drilled holes

## MATERIAL CHARACTERIZATION

Changes in mechanical and microstructural properties of materials significantly affected the UT parameters. Some of the key metallurgical properties that correlated with UT parameters are elastic modulus, hardness, fracture toughness, yield and tensile strength, grain size, and inclusion/porosity contents. Grain size is considered to be an important microstructural property that has a significant influence on the wave propagation in the material. Ultrasonic attenuation scattering coefficient ($\alpha_s$) is given by the equation:

$$\alpha_s = S_L D^3 f^4 \qquad (1)$$

where, $S_L$ is the scattering parameter depending on the wave modes used, $D$ is the mean grain size (material anisotropy), and $f$ is the frequency. From Equation 1, it can be understood that the ultrasonic attenuation (due to scattering) is exponentially proportional to the grain size and the frequency of the ultrasound used during the inspection. Other studies have also demonstrated ultrasonic velocity varies exponentially, and ultrasonic attenuation increases linearly as the hardness decreases [2–3]. Therefore, it is critical to understand the microstructure and hardness of the materials for ultrasonic NDE. The microstructure of the AMS steel is similar to cast stainless steel, i.e., coarse-grained, nonhomogeneous, and anisotropic in nature.

Figure 4 shows the metallographic examinations performed on the crossing diamond sample and has large austenitic grain. Grain size analysis was also performed per ASTM E112 using LAS X grain expert software. This tool applies specific two-dimensional algorithms to directly measure the grain area.

From this, the mean grain diameter for the diamond crossing sample was calculated as G = 0.8, which is the equivalent to 0.037 inches (0.94 mm). This is a fairly large grain compared to standard rail steel microstructure.

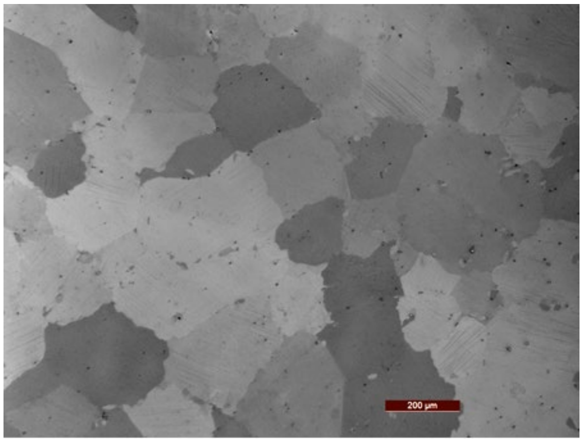

Figure 4. Microstructure of crossing diamond sample

Next, the microhardness measurement was conducted in the same sample using a microhardness tester. Hardness refers to the material resistance to plastic deformation. The microhardness tester uses the same principles as the macrohardness tester, but on a smaller scale. It can detect small variations in hardness that are caused by overheating or mechanical deformation. Figure 5 shows the Vickers hardness (HV) obtained for the crossing diamond sample with a 300 g load. From this, it is evident that the crossing diamond sample exhibits a hardness gradient, which is the result of the explosive hardening process that is usually done on the railroad AMS steel castings.

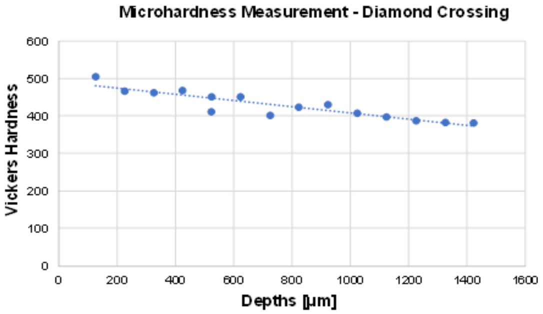

Figure 5. Microhardness measurement test result

## ULTRASONIC TESTING RESULTS

The research team considered low-frequency hand-held UT approaches for these initial trials. First, 500 kHz UT measurements were conducted, and Figure 6 shows the results.

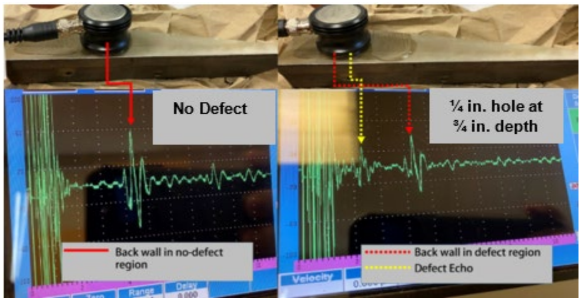

Figure 6. 500 KHz UT results in crossing diamond sample

Reflectors were large enough to produce a detectable signal echo. Signals were clear for the holes in the wider sections. In the narrow section (tip of the diamond sample), the footprint of the currently used transducer could influence the results; however, some echoes were visible. Next, a 2.25-MHz test was conducted, with Figure 7 showing the results. The ultrasonic signal response on the 0.75-inch (19 mm) depth through-hole was about 26 percent and the signal echo was detectable. The low-frequency UT findings demonstrated that utilizing low-frequency UT NDE methods could be useful for characterizing internal flaws in crossing diamond samples that have coarse grain structures

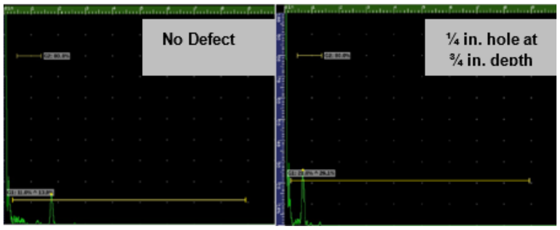

Figure 7. 2.25 MHz UT results in crossing diamond sample

## CONCLUSIONS

The microstructure of an AMS crossing diamond casting revealed a coarse grain microstructure. Application of low-frequency UT findings demonstrated that using low-frequency UT NDE methods could be helpful for characterizing internal flaws in crossing diamond samples that have coarse grain structures.

## FUTURE ACTION

Future efforts will continue to explore more low-frequency UT and electromagnetic NDE approaches. The microstructure of the AMS crossing diamond sample can be used for ultrasonic modeling and simulation exercises, which will be helpful to determine the best ultrasonic parameters. Future action should include evaluating additional samples for variation. Finally, further efforts should focus on creating a special trackwork test sample standard for validating alternative NDE technologies.

## REFERENCES

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## KEYWORDS

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