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A WIRE INDENT PROFILING SYSTEM FOR THE ASSESSMENT OF CROSSTIE BOND AND SPLITTING PROPENSITY

SUMMARY

This research result highlights a significant outcome from a task within a larger research project entitled, "Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials." This research is performed by Kansas State University (KSU) and sponsored by the Federal Railroad Administration (FRA). The project started in 2015 and will continue through Spring 2019.

This report highlights the development and testing of an automated, high-resolution, non-contact wire indent profile measurement system designed to measure geometric parameters of prestressed concrete reinforcement wire. This tool measures wire features that have a relationship to the bond and splitting performance of concrete crossties.

This new technology overcomes the limitations of manual measurement techniques. The system can measure large segments of wire to yield statistically significant samples of indent parameters including indent depth, sidewall angle, sidewall area, and volume. This system represents a valuable tool to aid in identifying the key indent geometry features related to transfer length and cracking propensity, thereby ensuring high-quality bond and eliminating the potential for in-track tie splitting failures.

BACKGROUND

The transfer length is a key diagnostic parameter for railroad evaluating pretensioned concrete railroad ties and represents a valuable quality control parameter.

Research indicates that the geometry of the prestressing wire indents influences the transfer length as well as the onset of cracking and splitting. This is particularly important in the manufacture of concrete ties intended for high-speed and heavy-haul rail applications. Cracking and subsequent de-bonding of prestressing wires can result in severe splitting and even complete tie failure (Figure 1). Therefore, both transfer length and cracking propensity are important variables to control during concrete tie design and manufacturing.

Figure 1 : In-Track Crosstie Failure

The wire specifications in the current standard are intended to promote the manufacture of quality prestressed railroad ties (ASTM A881, 2016). However, the current standard does not address the detailed causes of splitting failure because the specific indent features responsible for cracking are not yet quantitatively identified.

A key reason for the lack of understanding of the indent features directly responsible for cracking and subsequent tie failure is that measurements of these features is a very difficult task. The tests identified in the current standard are relatively crude, and limited to manual assessment procedures with mechanical instrumentation. These slow manual measurements precluded investigation into the quantitative influence of indent features.

Indented wire is manufactured by pulling wire through a set of three rollers, oriented 120 degrees apart. Indent shapes and detailed geometries can vary widely. Each roller has many contact teeth that indent the surface of the wire in a regular pattern. Therefore, sampling only a few indents, on a small segment of indented wire, severely restricts the ability to statistically characterize the effect of multiple wire indents on a long length of wire. Figure 2 shows a typical set of indent rollers and a typical chevron indent pattern. Rollers are subject to wear, and may require replacement after extended use or damage to the teeth.

Indent Roller **Typical Indent**

Figure 2: Manufacture of Wire Indents

OBJECTIVES

The overall objective of this work is to create a tool to aid manufacturers, researchers, and others in the assessment of wire indent parameters during the general design phase process, before ties are manufactured. The tool can also be used for quality control activities during serial production. The data from this tool, in combination with the concrete properties, will help users achieve a desired transfer length (bond) while avoiding cracking (splitting failure).

METHODS

A schematic diagram illustrating the wire indent measurement system is shown in Figure 3. It consists of a commercially available laser profilometer, which measures the profile shape along the longitudinal surface of the prestressing wire under test, extending over multiple indents.

The extraction of features associated with a typical single indent, from the composite of a sequence of high (nominally 2 microns) resolution slices, is shown in the upper right-hand corner of the figure. The scanning head captures depth profiles over a longitudinal distance of 15 mm, which is sufficient to capture about six indents around the circumference of the wire as the wire is rotated through a complete revolution.

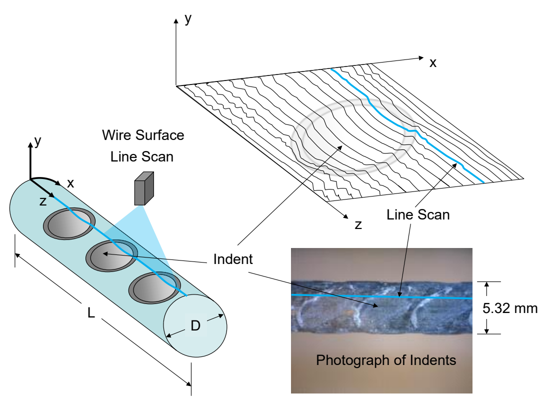

Figure 3: Indented Wire Measurement

Figure 4 shows a photograph of the overall LabVIEW-based indent scanning system. The system is capable of measuring wire lengths up to 28 inches, which is sufficient to capture a full rotation of the roller. The angular feed of the support platform (lathe) has an optical encoder with maximum resolution of 7,200 positions (profiles) per 360 degrees. The traversing system utilizes wire alignment bushings to control the inherent bend in the wire introduced when spooled by the manufacturer. Heat maps for each 360-degree scanned segment (see

Figure 4). are stitched together to form a complete scan over the length of the wire.

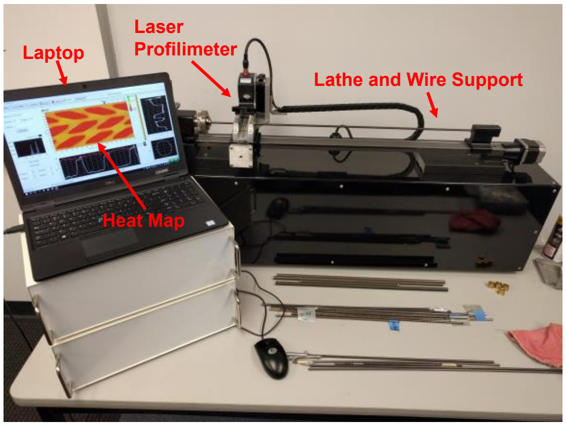

Figure 4: LabVIEW-based Indent Scanning System

RESULTS

Figure 5 depicts four, three-dimensional (3D) geometric features identified as key to characterizing the bond (transfer length) and cracking (splitting propensity) of a typical indent pattern. Figure 6 shows a typical row-by-row histogram comparison of indent sidewall angle, made possible because of the large statistical sample of indents from the profiling system. The system outputs histogram statistics of all relevant indent features.

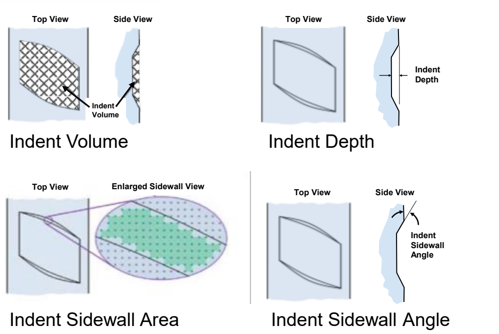

Figure 5: Key 3D Indent Geometrical Features

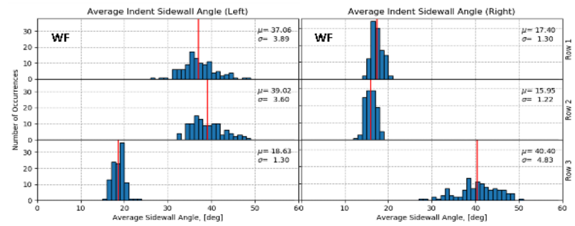

Figure 6: Sidewall Angle Histograms

Correlations for transfer length (TL) and total crack length (CL) as a function of the key indent features have been developed from prism tests with varying amounts of concrete cover (Savic, et al., 2018). Figure 7 shows that transfer length is well correlated with indent volume, sidewall area, and concrete release strength.

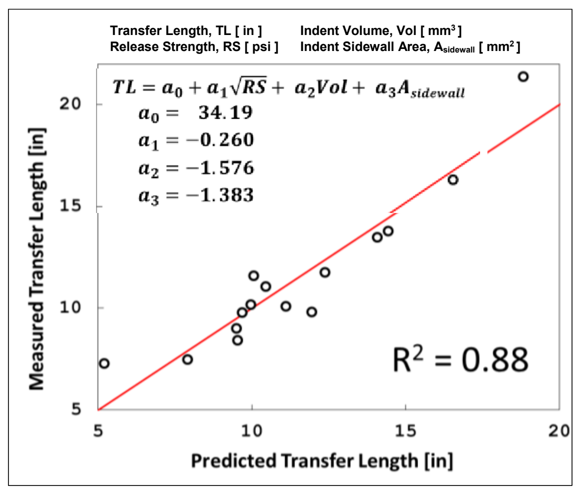

Figure 7: Correlation for Transfer Length

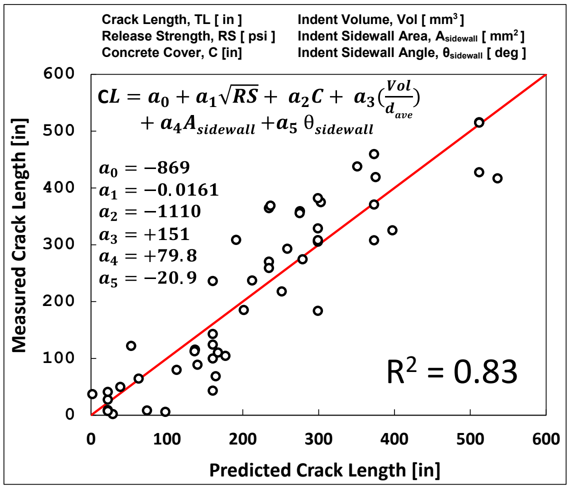

Figure 8: Correlation for Crack Length

Figure 8 depicts the correlation of measured crack length, CL, as a function of the key indent parameters average indent volume, average indent depth, average sidewall angle, and average sidewall area, along with concrete cover and release strength. The R^2 values of 0.83 or higher indicate a high degree of correlation.

CONCLUSIONS

KSU developed a state-of-the-art, non-contact optical wire indent profiling system for measuring the indent geometry of prestressing wires. The system precisely measures geometric characteristics of long segments of wire to yield statistically significant samples of all indent parameters, including indent depth, sidewall angle, sidewall area, and volume. These key indent parameters were then used to determine high R2 correlations for transfer length and crack length as a function of the indent geometry, cover, and concrete release strength for a series of prestressed prisms. This tool is a valuable aid in identifying the key indent geometry features related to transfer length and cracking propensity, thereby ensuring high-quality bond and eliminating the potential for in-track tie splitting failures.

FUTURE ACTION

KSU is currently developing a wire-indent optimization strategy for pretensioned concrete railroad ties that incorporates the recent correlations for bond (transfer length) and splitting propensity (crack length) as a function of the key indent parameters.

REFERENCES

ASTM A881/A881M-16a (2016). Standard Specification for Steel Wire, Indented, Low-Relaxation for Prestressed Concrete.

Savic, A., Beck, B. T., Robertson, A. A., Peterman, R. J., Clark, J., Wu, C. (2018). Effects of Cover, Compressive Strength, and Wire Type on Bond Performance in Prismatic Prestressed Concrete Members, *JRC2018-6153*.

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KEYWORDS

infrastructure, railroad ties, indented wire geometry, transfer length, cracking and splitting, prestressed concrete, high-speed rail