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Evaluation of Premium Insulated Rail Joint Designs in Revenue Service Testing

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Premium insulated joint (IJ) designs continue to perform well in heavy service mainlines. With support from Transportation Technology Center, Inc. (TTCI), participating Class I railroads, and insulated rail joint manufacturers, an evaluation of several premium IJ designs is being conducted under high traffic volume mainline track conditions. This industry effort has produced some innovative designs that are now being evaluated at several revenue service test locations. These tests allow for comparable evaluation of new designs under a range of demanding revenue service conditions.

Rail service life continues to increase as better steels and maintenance practices push the limits of rail performance. As a result, there is an opportunity to increase system efficiency further with longer lived IJ in heavy axle load (HAL) service. This *Technology Digest* is one of a series on technology implementation conducted by TTCI under the AAR Strategic Research Initiatives Program.

Service lives of standard IJ designs in mainline service are 500 MGT (typical service warranties). The goal of this research is to support the development of premium IJ with extended lives up to and beyond 1,000 MGT. Ideally, an IJ would provide, with minimal maintenance, a service life closer to that of the parent rail. However, because of its design characteristics it is subjected to a more severe service environment and is considered a weak link in the track system; especially in HAL service.

STANDARD INSULATED JOINT DESIGNS

Standard IJ comprise the majority of IJ in mainline HAL service today. As technology and practices evolve, so does the definition of a standard IJ. The current standard IJ typically has the following features:

- Butt joint design.
- 36-inch, six-hole joint bars.
- Improved performance insulation (e.g. Kevlar®).
- Shock resistant epoxy.
- Service life warranty (duration and/or MGT, typically three years or 500 MGT).

Key Findings:

- With the average service life of rail increasing, an opportunity to improve IJ life is shown to be feasible in this research.
- Revenue service test results show that the high-modulus design is providing more than 1,000 MGT service lives under HAL traffic. The failure modes of each design were documented and include:
  - Epoxy failures.
  - Bar and bolt cracks/breaks.
  - Rail end chipping.
  - Design-specific failure modes (e.g., rail vertical alignment on Long Angle Projection™ or LAP joints).

  While these are often inter-related, epoxy failure no longer is the predominant initial failure mode.
- The Center Liner® designs show little variability in service life. This is desirable for maintenance planning.

PREMIUM INSULATED JOINT DESIGNS

Premium design IJ generally have additional features that are intended to provide improved durability, improved dynamic performance or both; especially to extend service life under heavier loads. Some features include:

- Lapped rail joints.
- High-modulus joint bars (e.g., varying cross-section bars).
- Improved rail support (e.g., supported end post).
- Alternative methods of load transfer between rails (e.g., keyed bars, ceramic end posts).

REVENUE SERVICE TEST

A large-scale revenue service test of premium IJ designs was established by railroads in New Mexico, Nebraska, and West Virginia. The subdivisions selected for evaluating the IJs have demanding operating environments. Dynamic loads are high with a mixture of 39-, 36- and 33-ton axle trucks and trains traveling at 60 to 70 mph.

There is a good mixture of track component designs, with concrete and timber crossties and various elastic fasteners. The track foundations are generally competent, with good drainage at most locations. The rail is continuous welded rail (CWR) with few joints.

Insulated joints of various premium designs were installed in track as needed over the past 10 years. The performance of the IJ has been monitored with yearly or more frequent inspections. During the inspections, the evidence of degradation modes and any other contributing track issue is documented. In addition, attempts are made to determine the reason for removal by interviewing the local track inspection and maintenance personnel and examination of removed IJs when available.

Table 1 lists IJ designs and number of replicates in test.

INSULATED JOINT SERVICE LIFE PREDICTIONS

The service lives of the IJ in the study are determined by inspection at the test site on an annual or semi-annual basis. Each IJ is inspected, with the condition of the IJ and surrounding track noted. If the IJ has been removed, the earliest weld date on the replacement is used as the removal date. When available, the removed IJ are examined to determine the failure mode(s) that caused removal from track. The service life data, using both removed IJs and surviving IJs, is used to determine a likely range of median service lives for each design in the test. Table 2 shows the predicted service lives for each IJ.

Table 1. IJs in the service life study

Design	No. in Test	Description
Center Liner®	68	Butt joint, 48″ bars, non-epoxied insulation near center
High-modulus Bars	28	Butt joint, 36″ bars that are forged and wider in center
Ceramic End Post	15	Butt joint, 36″ bars, end posts with ceramic disks
Epoxy	11	Butt joint, 36″ bars, experimental epoxies
Short Angle Projection™	9	Lapped joint, rails do not have point slopes
Long Angle Projection™	18	Lapped joint, rails have point slopes
Keyed	12	Butt joint, mechanical keys between rails and bars

Table 2. Predicted median service life (MGT) by IJ type

Type	Censored	Failures	95% Confidence Interval for Median Tonnage to Failure
Center Liner®	45	23	684 – 889
Ceramic End Post	3	12	467 – 730
Keyed	6	6	359 – 561
LAP Joint™	8	10	357 – 650
High-modulus	23	5	526 – 1081
Epoxy 1	3	4	416 – 953
Epoxy 2	0	4	285 – 709
Type	**Censored**	**Failures**	**95% Lower Bound for Median Tonnage to Failure**
SAP Joint™	7	2	433

A survival analysis is carried out to reach these confidence intervals using both censored data (IJ that are still in service today or IJ that were taken out for non-failure related circumstances) and failure data records. These intervals can be calculated with either the least squares estimation method (LSE) or the maximum likelihood estimation method (MLE). The first is done by using a regression fit of the deviation of the data points. The latter determines the parameters of the likelihood function that would most likely form the data. MLE is used because it is more accurate overall, especially when the failure count is small.

The data was analyzed with two different distributions: logistic and Weibull-Bayesian. Logistic is used when a sufficient amount of failures have occurred. The former gives a confidence interval, the latter a lower bound only. These boundaries give the previously listed projected lives of the IJ. This is to say that there is a 95 percent probability the population median falls between the upper and lower bounds of these windows given the available data.

For example, given the 23 failures so far, the analysis says that the overall median life of a Center Liner has a 95 percent chance of being between 684 and 889 MGT. Keep in mind this window can move with each failure accumulated. Looking into similar past analyses, the change in the predicted life window can be seen in Figure 1. This chart shows the need to run full life cycle testing of new components. In this case, the design has shown no new failure modes in later service life. The service life estimate has remained steady with additional tonnage. Had another failure mode emerged, the service life estimate would drop with additional tonnage.

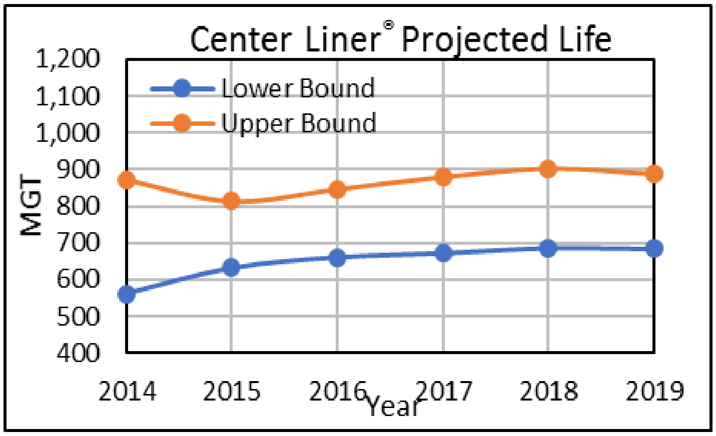

Figure 1. Center Liner projected life

Note that the median service life estimates for the second group in Table 2 are based on few failures or small populations. These estimates are the most subject to change as additional tonnage and failures occur. The High-modulus bar and SAP joints are some of the most recently installed IJ in the test. Thus, additional tonnage is needed to fully evaluate most of these designs.

FAILURE MODE DESCRIPTIONS BY TEST DESIGN

Table 3 lists the failure modes noted for each IJ design in the test. Following the table is a description of each failure mode. Typically, a design which exhibits one failure mode has the potential to be improved. Whereas a design with several failure modes may be nearly optimized.

Table 3. IJ failure modes observed

Design	Rail End Chipping	Epoxy Failure	Bolts/Bar Failure	Other
Center Liners®	X	X		
High modulus bars	X	X		
Ceramic end posts	X			
Epoxy	X	X		
Short Angle Projection™				X[2]
Long Angle Projection™	X	X	X	X[1]
Keyed			X	

[1] Rail alignment during assembly

[2] Failure modes were not determined

TYPICAL FAILURE MODES OBSERVED

Rail end chipping: Rail end cracking and chip-outs associated with plastic flow of the rail ends at the end post of the joint. Figure 2 shows rail end chipping.

Epoxy failure: The epoxy debonds from one or both rails sufficient to result in longitudinal movement of the bars with respect to one rail.

Bolt/bar failure: Fracture of one or more bolts and/ or cracking of one or more joint bars.

Other: The LAP design requires higher manufacturing tolerances due to the lapped joint and point slopes on each rail. Slight misalignments of the two rails or variance in the point slopes can result in the wheel transfer zone being reduced to that of a butt joint. Figures 3 and 4 show LAP joints with good and poor rail transfer zones.

Figure 2. Rail end chipping on a butt jointed IJ

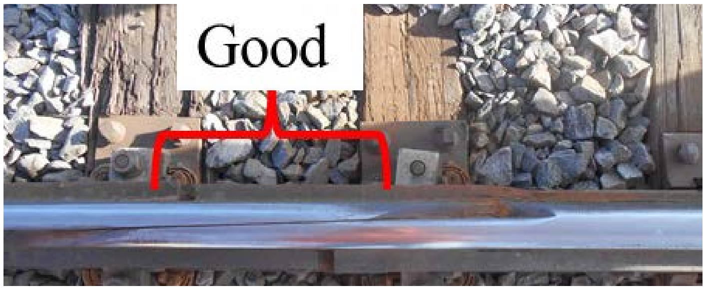

Figure 3. Good wheel transfer zones on LAP IJs

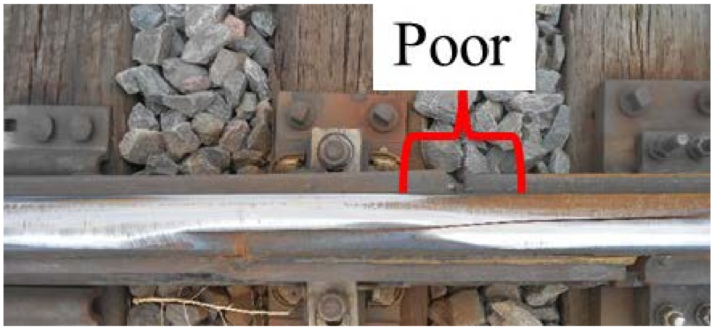

Figure 4. Poor wheel transfer zones on LAP IJs

Summary

The projected mean service lives of several premium IJs remain steady with additional testing. And while some designs have accumulated enough failure data to predict service lives in the range of 1,000 MGT, continued monitoring is required to understand the full spectrum of each design's mean life to failure and primary failure mode as referenced in Table 2. Therefore, this research effort should continue evaluating new failure data from the IJ test bed to support the introduction of premium IJs into HAL service.

Acknowledgements

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