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## Development of an Improved Performance Bonded Insulated Joint for HAL Service

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### Summary

Under the Association of American Railroads' (AAR) Strategic Research Initiative Program, Transportation Technology Center, Inc. (TTCI) has designed an improved performance bonded insulated joint (IJ) for prototype development and testing. The design was developed from observation of current designs, failure mode analysis, stress analysis, and modeling work.

TTCI identifies impacts from wheels as a significant root cause of IJ failures. The other factors, which induce distress into the IJ components, are higher deflections and longitudinal forces. The combined effect of these factors is to load the epoxy (which bonds the IJ together) beyond its capacity. The resulting failure mode, an "unzipping" of the epoxy, shortens service life of the IJs to less than 200 MGT under 286-kip coal traffic. It also causes significant service disruptions on some of the most heavily used freight lines in North America.

The AAR/TTCI design will address these problems. The prototypes are undergoing testing at the Facility for Accelerated Service Testing (FAST). To date the prototypes are performing well, but the long term performance of the design is not known. The new IJ design is expected to have the following benefits:

- Reduced running surface generated impacts due to a smooth wheel transition over an angled cut rather than a butt-joint
- Further mitigation of impacts by added damping with larger wood ties or concrete ties with rubber pads
- Increased capacity for longitudinal thermal forces due to an additional epoxied surface
- Lower deflections due to increased joint stiffness above surrounding rail
- Up to a two third reduction in epoxy shear stresses, mainly due to absence of shear lag

This premium IJ is expected to not only increase the service life of IJs under heavy axle load service but also provide superior ride quality. As an additional benefit, impacts induced into the trucks and carbodies by the standard butt-jointed IJ may also be reduced.



**INTRODUCTION**

Bonded insulated joints (IJs) have shorter lives in heavy axle load (HAL) routes in comparison to some other track components. For example, IJs have a service life of 150 to 300 MGT<sup>1</sup> in comparison to tangent premium rail, which has a service life of 1,000 to 2,000 MGT. This shorter life has reduced service reliability and increased train delays.

With funding from the AAR and working with railroads and suppliers, TTCI has developed an understanding of HAL service environment and failure modes of IJs, which has led to an improved current IJ design.

Impacts from wheels at the running surface discontinuity are significant factors in most of the failure modes. According to an ongoing TTCI study of low impact foundations for Special Trackwork, the impacts are of two types: 1) High frequency and 2) Low frequency.<sup>2</sup> High frequency impacts affect the IJ components, such as bolts, bars, and epoxy. Low frequency impacts affect the foundation. As a result, the components distress, ballast degrades, and joint deflection increases. This condition causes components to un-bond, crack, and break.

Recent IJ designs address only strength improvement of its components. This improvement does not change the basic character of IJs, and thus may not increase service life significantly. A running surface discontinuity is always present, which causes impacts.

On the basis of inspections of failed IJs, analysis, and modeling work, TTCI has identified the following four areas of improvement with regard to improved IJ design:

**1- Reduce or Mitigate the Effects of Impacts**

Figure 1 shows that the vertical dynamic load spectrum at FAST is relatively low compared to revenue service. The documented service life of a butt-jointed bonded IJ is more than 400 MGT at FAST, compared to 150 to 300 MGT in HAL service.<sup>1</sup> The track at FAST is relatively well-maintained and high impact wheels are non-existent. This suggests that impacts from wheels and condition of track are important factors in the service life of IJs.

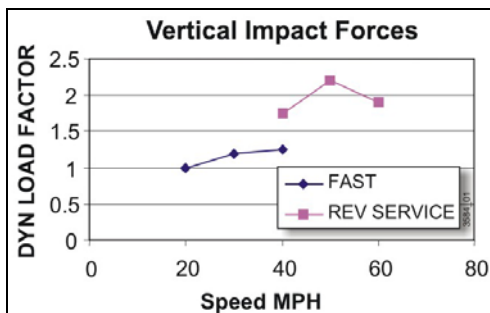


Figure 1. Comparison of Vertical Impact Forces

Providing a smooth running surface profile from one rail to the other can reduce impacts. This approach has successfully reduced impacts in some Special Trackwork applications such as turnout frogs and moveable bridge joints. Figure 2 shows that the impacts from a new thick web miter bridge joint are considerably lower than previously tested designs.<sup>3</sup>

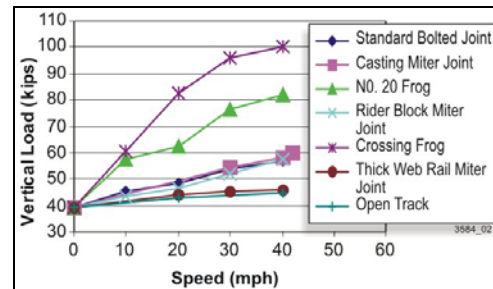


Figure 2. Comparison of Impacts from Miter Cut Joints and Other Special Trackwork Applications

Adding damping to IJ foundations is another way of mitigating impacts. According to a recent crossing diamond foundation study, the impacts from wheels can be mitigated up to 20 percent just by providing optimal damping.<sup>4</sup> To study the effects of damping on IJs, many conventional IJs have been installed at FAST over wider wood ties, closely spaced wood ties, and concrete ties with rubber pads. These tie configurations are expected to further reduce the impacts from the joint.

**2- Reduce the IJ Deflections**

The stiffness of conventional IJs changes abruptly at the end post to about one fourth of the rail section. When loaded, the IJ tends to have a “hinge” at this point, creating higher local stresses in the epoxy. Figure 3 shows that stresses near the end post, mainly due to shear lag, can be as high as 6,000 psi, almost double the design stress of 3,500 psi.<sup>5</sup> Consequently, the epoxy at the end post cracks aid in further reducing IJ stiffness and triggering higher deflections. Supporting the end post or reducing the tie spacing may help reduce deflections.

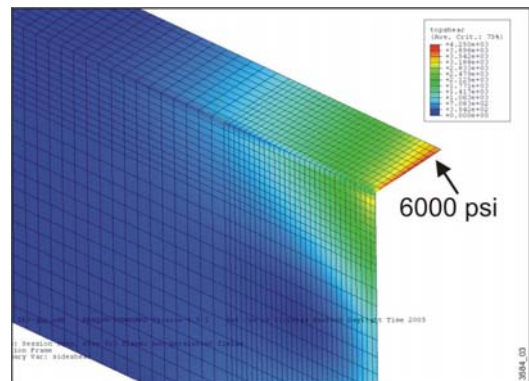


Figure 3. Stresses in Epoxy at the End Post of Butt-Joint

Different support systems are being tested at FAST to reduce the deflections. These include multi-tie plates and different tie configurations. Figure 4 shows that 12-inch-wide ties have reduced the deflections.

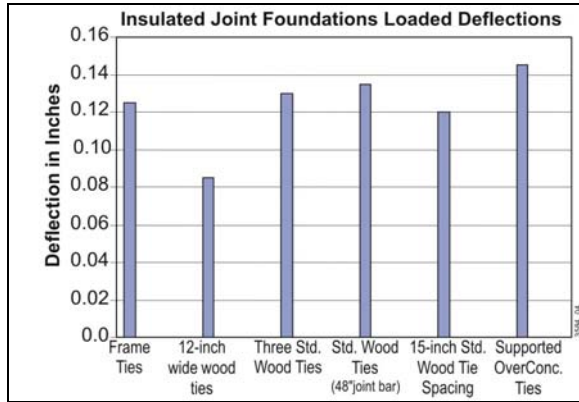


Figure 4. Comparison Loaded Conventional IJs over Different Tie Configurations

### 3– Mitigate Longitudinal Force Effects

Tensile longitudinal forces of 500 kips were measured in revenue service.<sup>6</sup> These temperature related stresses are additive to live load bending stresses. A railroad can control the longitudinal stresses in IJs to some extent with the selection of track materials, rail installation practices, train operations, and rail stress management policies. However, the over-riding concerns of train safety and capital efficiency bias towards high tensile forces in mainline rail.

Under current practices, fixed points such as bonded IJs are often locations with the highest tensile forces. The following guidelines assist in managing rail stresses:

- Review of track design (to prevent track buckling) – Because axle loads have increased and track components have become larger, a review of track buckling resistance should be conducted to ensure that the proper resistance to track buckling remains while minimizing required tensile forces in the joints.
- Anchoring – Rail around bonded IJs should be box anchored at every tie.
- Rail alignment – IJ plug rails should be well aligned with surrounding track to reduce the likelihood of an alignment defect or incipient track buckle.
- Rail joining – Careful control of rail consumption during flash welding is required to minimize raising local rail tensile forces.
- Fasteners – Use and maintenance of effective fasteners and defined rail seats at the IJ will ensure good track alignment and reduce the likelihood of alignment defects or incipient track buckles.

While reducing longitudinal forces is more demanding, making the joint more resilient might be an economical option. The recommended options are stronger epoxy, stronger insulators, and longer joint bars.

Figure 5 shows that IJ coupons with fiberglass insulators have higher shear strength than the coupons without insulator. Thus a stronger insulator, such as Kevlar®, may be used to increase the resistance of the IJ to longitudinal forces.

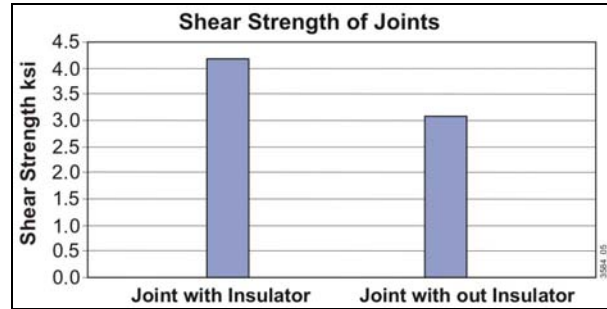


Figure 5. Shear Strength Comparison of IJ Components

### 4– Improve IJ Maintenance Practices

Due to running surface generated impacts and the weaker rail structure at the joint, IJ foundations tend to wear faster than typical track, requiring more frequent surfacing than normal track. Higher density traffic on coal routes has reduced the opportunity of timely preventive and proper foundation maintenance.

At the IJ end post, metal flows quickly due to sharp corners at the rail ends. In order to avoid shorting, the metal needs to be ground frequently. Due to possibility of damaging the fiberglass end post and gap widening, metal grinding skill at the rail end is particularly demanding. When the fiberglass end post is damaged, water penetrates into the gap corroding the steel and un-bonding the epoxy. When the gap is widened, the impacts increase and chipping/breaking occur at the corners. Thus, proper grinding of metal flow is important.

Figures 6 a and b show two joints with ground ends. The increased IJ gap shown in Figure 6a will increase impacts, reducing the IJ service life. Figure 6b is an example of good workmanship. The gap is maintained without damaging the fiberglass end post.

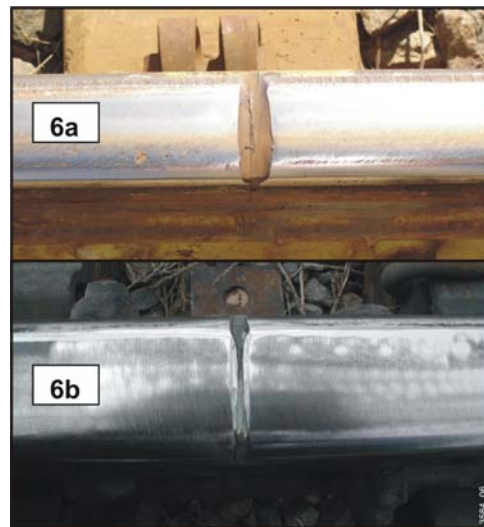


Figure 6a (top). Not Recommended Method  
Figure 6b (bottom). Preferred Method

Instead of sharp corners, a radius of 1/8 to 3/16 inch at the rail ends is recommended to reduce the metal flow and the need for rail end grinding.

## AAR/TTCI IJ DESIGN

Based on these four major areas of improvement, TTCI has pursued the development of a low impact angle cut IJ. As Figure 7 shows, the main feature of the design is the full section angle cut through the rail. This allows smooth transition of wheels from one rail to the other. It also provides higher resistance to longitudinal forces due to three layers of epoxy impregnated fiberglass and triple shear bolts in the middle. Commercially available bolts, epoxy, and insulators can be used with this design with little or no modification. The designs under development have angle cut lengths of 12 to 36 inches. This length will be optimized based on acceptable level of impacts, maintenance requirements, and ease of milling and assembling.

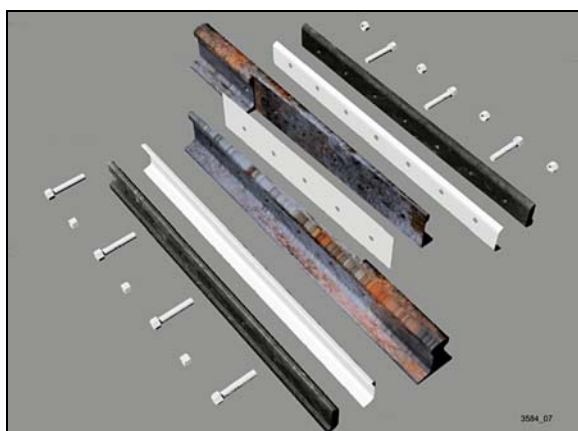


Figure 7. AAR Reduced Impact Insulated Joint

Figure 8 shows the stress contours of epoxy in an angle cut joint. The maximum stresses in the epoxy in angled cut joint were about 60 percent lower than the conventional joint. These stresses are within allowable limits, mainly due to the more efficient transmission of load across the two rails (i.e., absence of shear lag) in the TTCI/AAR design angled cut.

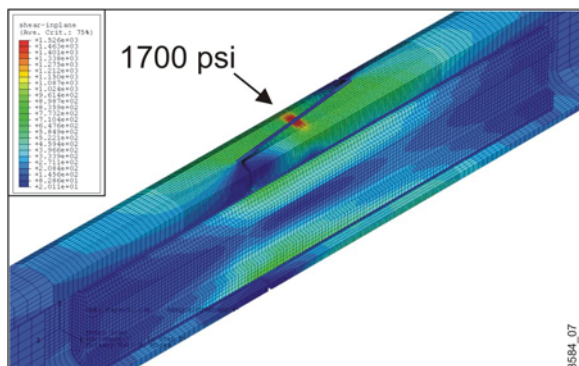


Figure 8. Angle Cut Joint Stress in Epoxy

Figure 9 shows the first AAR prototype angle cut joint, which was designed and developed out of 136 TW rail. It was installed at FAST and has about 40 MGT of traffic to

date. The angle cut is 18 inches long. The thickness of the rail ends is about 3/4 inch, which keeps the sharp rail end corners out of the wheel path. A gage side “point” slope of 1/8 inch over 3 and 6 inches on the obtuse and acute corners, respectively, keeps the wheel contact off the corners with relatively thin web support.



Figure 9. AAR Angle Cut IJ an H-Plate at FAST

One immediate observation of the joint is there is not enough space between the angle cut rails. Fine metal particles could accumulate between rails, shorting the joint.

## FUTURE WORK

In the next design iterations, the gap will be increased from 1/32 to 1/8 inch up to 3/4 inch depth of the railhead. The other observation is the need for optimum radius at the corners to reduce metal flow. Metal flow at the rail ends may need to be ground at similar or frequent intervals as frogs and switches. In future design iterations, the focus will be on controlling the metal flow by optimizing the corner radii.

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