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Improved Joint Bar Service Life — Manufacturing Processes and Materials

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Summary

Under sponsorship from Association of American Railroads' Strategic Research Initiatives (SRI) Program, Transportation Technology Center, Inc. is leading an industry-wide effort to improve the performance of standard joint bars in heavy axle load service environments. A multilevel approach to achieve this goal includes improving maintenance practices, refining manufacturing processes, increasing material strength, and developing a new joint bar profile. This *Technology Digest* (TD) discusses suggested improvements in the manufacturing process and the use of high-strength materials for joint bars.

The SRI study shows the following:

- The laboratory tests conducted on notched joint bars show that joint bars with either compressive or no residual stresses at the bottom are likely to grow cracks at a significantly lower rate than the joint bars with tensile residual stresses (as manufactured).
    - — Heat treatment methods to induce useful stresses were discussed in TD-11-016.
- Most joint bars are hot punched to make bolt holes. This process leaves rough surfaces inside the hole, which, in addition to the bolt-hole corners, are potential locations for crack initiation.
- Microstructure analysis of samples of the current joint bar material (AISI 1045 steel) shows excessive surface cracking and decarburization. Surface cracking is the most likely cause of joint bar fatigue failure.
- Yield strength and fracture toughness of AISI 4140 steel, a candidate material for new joint bars, are 50 and 100 percent higher than the current 1045 steel.
    - — The tempered martensitic microstructure of 4140 steel is expected to have better fatigue properties than the ferrite plus pearlite microstructure of 1045 steel.

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INTRODUCTION AND CONCLUSIONS

Detailed study of the rail joint bar service environment shows that, in general, current load conditions may exceed the yield and fatigue strengths of rail joint bars during their service lives, especially in cold weather when thermal stresses increase the magnitude of service loads.[1,2] Also, distressed foundations may induce higher stresses. This TD recommends strategies to increase joint bar service life by improving manufacturing processes and increasing joint bar material strength.

Besides increasing material yield and fatigue strengths,[3] laboratory tests have shown that useful (i.e., compressive) residual stresses, induced by heat treatment methods, can significantly reduce the rate of crack propagation at the bottom of joint bars. A joint bar with a crack growing at a slower rate has a higher probability of being detected and removed from track before breakage.

Most joint bars are hot punched to make bolt holes. This process leaves rough surfaces inside the hole, which are potential sources for crack initiation.

Microstructure study also suggests improvements in heat treatment methods to reduce significant surface cracking and decarburization found on production joint bars. The current joint bar 1045 steel has a ferrite plus pearlite microstructure. The microstructure is different at different locations on the same joint bar, indicating nonuniform heat treatment. Joint bars are heat treated to improve mechanical properties and to allow hole punching.

Laboratory tests have shown that 4140 steel has better yield strength and fracture properties than 1045 steel.

BACKGROUND

According to the accident database of the Office of Research of the Federal Railroad Administration, about one half of the broken joint bars that caused accidents had cracks initiated from bolt holes. The rest of the broken joint bars had cracks that initiated at the center of the top or the bottom of the bar. Joint bar cracks/breaks can be the result of rapid fracture or fatigue. A rapid fracture is caused when stresses in joint bars exceed the yield strength limit. Fatigue cracking is caused when stress amplitude and mean stress exceed the endurance limit of the material for prolonged periods.

As the result of large variations in foundation conditions, weather, and wheel conditions, total stresses in joint bars may vary significantly. Bending stresses between 20,000 and 60,000 psi have been measured in various track conditions. Residual and thermal stresses and stresses from other factors such as dimensional tolerances and contact stresses also occur.

Because of this variable load environment and the complexity of the joint design, one possible solution would be to use higher factor of safety for material strength. Improved joint bar design and higher strength materials are two options that can be used to increase joint bar strength. However, similar benefits may also be achieved by improving manufacturing processes and increasing quality control.

Effects of Useful Residual Stresses

Effects of residual stresses on yield and fatigue strengths of joint bars were analyzed in a previous TD.[3] To determine the effects on crack growth, various joints were tested in a rolling load machine (RLM). See Figure 1.

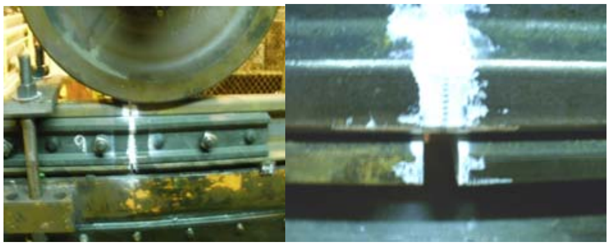

Figure 1. Rail Joint in RLM (left); Notch in the Bottom of Joint Bar (right)

The test matrix consisted of four rail joints with the joint bars types listed below:

- Rail Joint 1 – Control, as-manufactured joint bars
- Rail Joint 2 – Fully water quenched, compressive residual stresses on top and bottom
- Rail Joint 3 – Bottom half water quenched, top half air cooled—no residual stresses on top, compressive residual stresses on the bottom
- Rail joint 4 – Fully air cooled, almost zero residual stresses on top and bottom

All joint bars were of quenched 1045 steel and manufactured by the same vendor. Residual stresses of these joint bars were not measured, because the process is destructive. All these joint bars were from the same batch of which residual stresses were destructively measured on some of the joint bars.

One bar of each joint was notched using electrical discharge machining (EDM) at the bottom and the other was EDM notched on the top. Each joint underwent 500,000 cycles of 50,000-pound rolling wheel load. Crack growth was monitored at 100,000-cycle intervals for crack growth activity. As Figure 2 shows, a crack grew to 1.1 inches from the bottom notch in the control joint. No crack growth was observed in the other joint bars (i.e., fully water quenched, partially quenched, stress relieved, or fully air cooled). These results show that joint bars with either compressive or no residual stresses at the bottom are likely to grow cracks at a significantly lower rate than as manufactured.

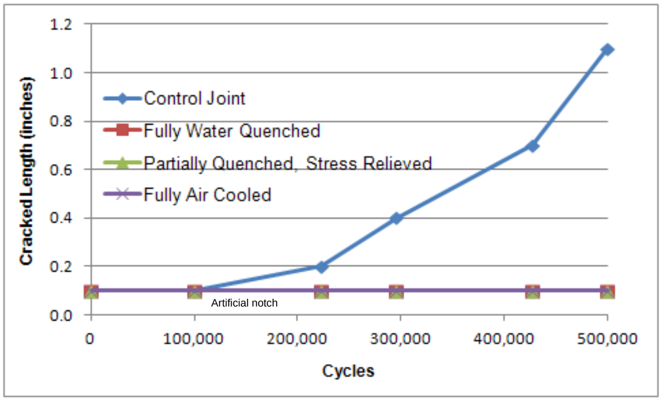

Figure 2. Crack Growth from Notched Joint Bars

Joint Bar Hot Punching

Typically, the cracks at the bolt holes initiate at the hole edges due to stress concentration. However, as Figure 3 shows, a crack initiated from the middle depth of the hole on one joint bar that was removed from track at the Facility for Accelerated Service Testing (FAST).

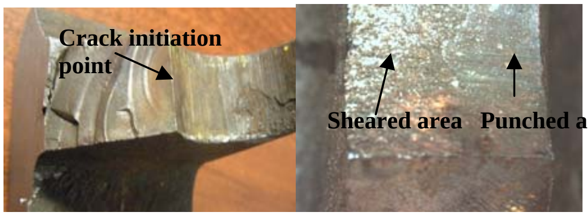

Figure 3. Crack Initiated from Middle Depth of Bolt Hole

Holes in this joint bar were punched while the joint bar was still hot. During the process, the hole was partially punched and the rest of the area was sheared off, leaving a rough surface. The crack likely initiated from this rough surface. Proper joint bar cold-hole drilling and reaming the edges and inside surface may reduce the likelihood of cracking.

Microstructure Analysis

The microstructure of the standard joint bar manufactured from 1045 steel is ferrite (light etching) plus pearlite (dark etching). Figure 4 shows the surface of the joint bar was decarburized, which is indicated by the lighter etching toward the surface.

A microhardness survey of the 1045 steel bar also corroborated the decarburization. Even though the depth of decarburization was lower than or at the maximum American Railway Engineering Maintenance-of-Way (AREMA) requirement, in general, decarburization can reduce the fatigue strength of material significantly.

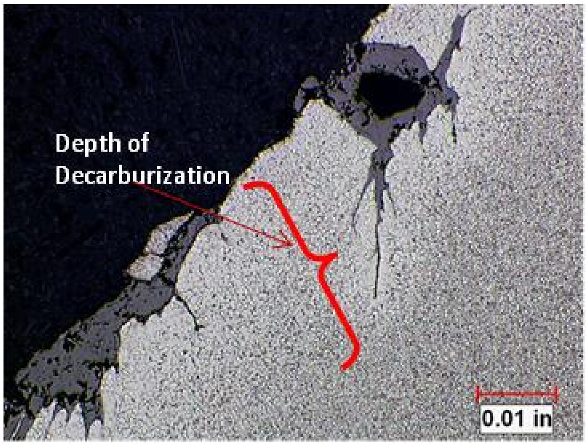

Figure 4. Microstructure Ferrite (light) plus Pearlite (dark) of 1045 Steel x 50*

The most important observation of the microstructure examination was the amount of surface discontinuities/cracks in the 1045 steel. A few cracks can be seen in Figure 4. Regardless of the mechanical properties of the steel, a bar containing surface cracking of this nature would be prone to failure due to fatigue. The cracks create sharp stress risers, which are probable fatigue initiation points. The combination of surface cracks and the reduced strength of the material due to decarburization increase the likelihood of fatigue initiation.

Comparatively, 4140 steel has tempered martensite structure, which may have better fatigue strength than ferrite plus pearlite microstructure of 1045 steel. Also, no decarburization was observed on the surface of 4140 steel (Figure 5). In addition, the microstructure was the same throughout the cross section.

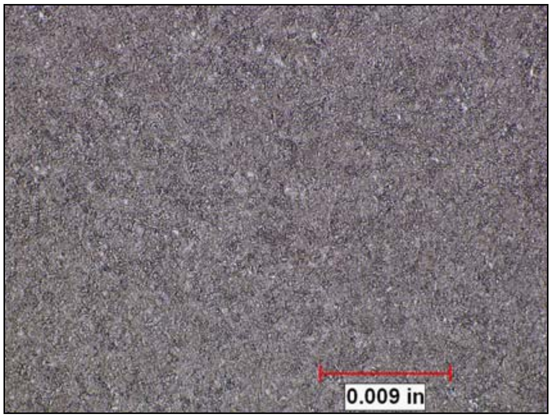

Figure 5. Near Surface Microstructure, Tempered Martensite, of IJ, 4140 Steel x 100*

* Microstructure analysis was conducted by the research and test department of BNSF.

In the current joint bar material (1045 steel), elimination of surface cracking and reducing the depth or eliminating the decarburization are key areas of improvement that can increase the fatigue resistance of current joint bar designs. These improvements are possible by refining the current manufacturing methods of joint bars.

Improved Joint Bar Materials

AREMA recommends a minimum of 70,000 psi yield strength for joint bars. Older joint bars (manufactured in the 1970s or '80s) have yield strengths of 85,000 psi. Current joint bar materials have yield strengths up to about 95,000 psi. Joint bar failure could be the result of material flaws or simply because the service loads exceed material strength. Many joint bars fail because of fatigue as well as fracture.

A detailed joint bar load environment study showed that, in general, the sum of all service loads, i.e., wheel live stresses and the thermal and residual stresses, may exceed joint bar strength. Due to the complexity of rail joint design (6 bolts, 12 holes, 2 joint bars, etc.), a higher design factor for safety is recommended, meaning higher strength steel should be considered for joint bars. Table 1 shows that 4140 quenched and tempered steel, a possible alternative to current 1045 joint bar steel, has superior yield strength and toughness than the current joint bar material.

Table 1. Mechanical Properties of Materials

Manufacture Date (material)	No.	BHN	YS 0.2% ksi	UTS ksi	Charpy (at 32°F) ft-lbs
1970 (1045 steel)	1	209	89	135	4
	2	204	77	125	3
	3	195	88	136	6
	AVG	**203**	**84**	**132**	**4**
2008 (1045 steel)	1	222	94	132	15
	2	224	94	139	7
	3	230	94	135	16
	AVG	**225**	**94**	**135**	**13**
2010 (4140 steel)	1	349	144	161	26
	2	362	144	160	23
	3	355	144	160	22
	AVG	**355**	**144**	**160**	**24**

BHN = Brinell hardness
YS = Yield strength
UTS = Ultimate tensile strength

Four high strength joint bars (two rail joints) machined with 4140 steel with the current AREMA profile have been installed at FAST. These test joint bars were installed in a section of track with marginal support conditions where many standard joint bars (1045 steel) had broken. The test joint bars made of higher strength material have accumulated 50 MGT. No signs of distress have been observed.

Future Work

The results of the research will be shared with AAR member railroads and their joint bar suppliers for implementation. Options to reduce bolt-hole damage during manufacturing will be studied. If proof testing of 4140 steel joint bars at FAST is successful, revenue service testing will be conducted.

Improvement in railway safety, reliability, efficiency, and capacity is the goal of the SRI Program. Life cycle testing of the joint bars will be performed to assess the benefits of improved performance joint bars on these four goals. Understanding the likely joint bar failure modes is a key output of life cycle testing. From the technical analysis, a cost-benefit analysis can be conducted to determine if and where improved performance joint bars should be used.

REFERENCES

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