TECHNOLOGY DIGEST
TD-11-016
©MAY 2011
TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Residual Stress Management of Rail Joint Bars

Muhammad N. Akhtar and David D. Davis

Summary

Residual stresses strongly influence the response of mechanical components to external loading. Residual stresses have been managed successfully in other industries to increase component service life. Transportation Technology Center, Inc., under the Association of American Railroads' Strategic Research Initiatives Program, has studied management of residual stresses in joint bars. More controlled management of residual stresses is likely to improve joint bar service life.

The following observations have been made:

- Significant residual stresses are present in some as-manufactured joint bars.
- Depending on the compressive or tensile nature of residual stress, a positive or a negative effect on the failure behavior of joint bars can be achieved.
- Inducing compressive residual stress at the bottom of the joint bar, which is mainly a tension area, has the potential to reduce total stress-state.
- Neutralizing residual stress on top of the joint bar, where contact stresses often exceed compressive yield strength, may reduce or eliminate the metal flow cracks under the railhead ends at the center of the joint.
- Proper residual stress management is a better option to increase joint bar strength and fatigue life as compared to increasing material strength or size.
- Proposed methods to manage residual stresses do not require significant changes to current manufacturing processes. They may also be applicable to joint bars reclaimed from service.

Please contact **Muhammad Akhtar (719) 584-0515** with questions or concerns regarding this *Technology Digest.* E-mail: muhammad_akhtar@ttci.aar.com.

Introduction and Conclusions

Current bolted joint bars are not designed for infinite fatigue life in the heavy axle load traffic load environment in continuously welded rail. Three options to increase joint bar service life are as follows: (1) Increase joint bar cross-section, (2) Increase material strength, or (3) Manage residual stresses that are induced during the manufacturing process. The first option is likely to increase the adverse effects of the difference in stiffness between plain rail and the joint assembly. The effects are similar to bridge and approach problems. The second option may not be economical. The third option can be adopted without changing the current manufacturing processes. This *Technology Digest* studied the procedures to neutralize or induce beneficial residual stresses that will increase joint bar strength.

The residual stresses at the bottom of the joint bar are tensile and approximately equal to the magnitude of tensile bending stresses from live loads. Neutralizing stress at the bottom may increase the bending strength. In addition, by inducing compressive residual stresses at the bottom, further bending strength benefits will likely be realized.[1] In other industries, residual stresses have been managed successfully to increase the fatigue life of components.[2]

Experiments show that residual stresses can be neutralized on the tops and bottoms of joint bars by heating to 1150°F and subsequently, cooling at room temperature. By heating to the same temperature but water quenching the full joint bars, an average of 15,000 pounds per square inch (psi) compressive residual stresses were induced on the top and bottom of the joint bars. By combining these two processes in the same joint bar (i.e., water quenching the bottom and air cooling the top half), residual compressive stresses of 15,000 psi can be induced at the bottom, and the residual stress on top can be neutralized. Joint bar top surfaces normally show plastic flow due to high compressive contact stresses. A zero residual stress on top is likely to reduce this metal flow.

Background

In addition to cracks in the bolt holes, significant numbers of joint bars fail due to cracking or breaking in the center. Joint bar breaks can be either brittle fracture or fatigue induced. Brittle fracture is caused when stresses in joint bars exceed the yield limit. Fatigue cracking is caused when stress amplitude and mean stress exceed the endurance limit of the material for prolonged time periods. Proper residual stress management can reduce the total and mean stresses.[3]

Due to large variations in foundation, weather, and wheel conditions, total stresses in joint bars may vary significantly. At the Facility for Accelerated Service Testing, typical values for bending and thermal stresses are 20,000 and 15,000 psi, respectively. Figure 1 shows the theoretical effect of residual stresses on typical load environment. When residual stresses are zero, the only stresses in joint bars are due to bending and thermal loads. Similarly, compressive residual stresses may offset tension stresses due to thermal changes, leaving only bending stresses in joint bars. In both cases, some brittle fractures may be avoided that occur due to joint bar stress exceeding the material strength.

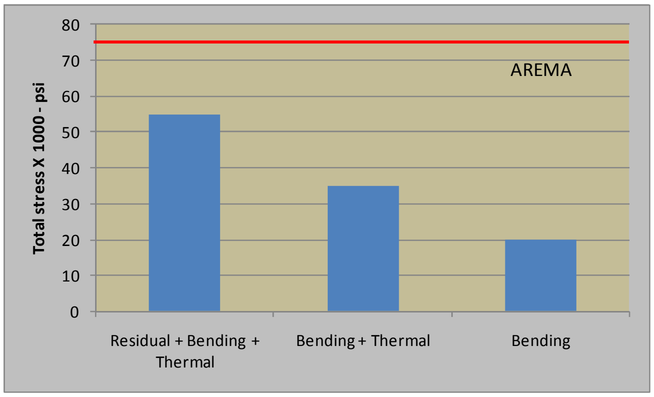

Figure1. Effects of residual stresses on total stresses

Residual Stress Measurement

Strain gages were installed along the height of joint bars and around bolt holes where residual stress measurement is required. Using a destructive measurement method, the joint bar was then saw cut at 1/8th inch from the edge of the strain gage. The difference in strains before and after the cut is the residual strain.

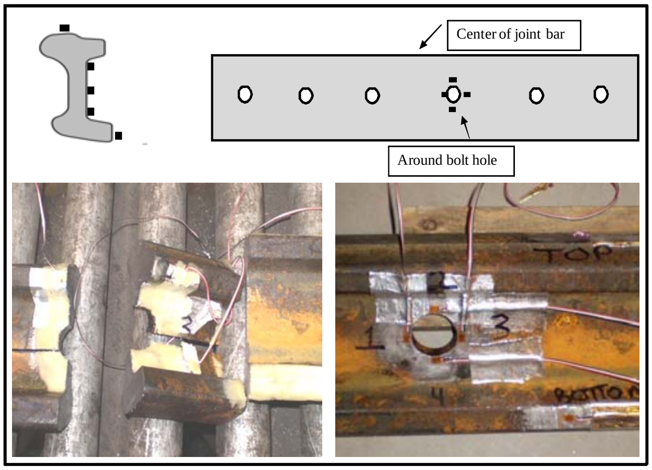

Figure 2. Strain gage and saw cut locations

The joint bar manufacturing process starts with cutting long pieces of rolled sections into 36- or 48-inch-long bars. Holes are punched after heating to the desired temperature and before water/oil quenching. After quenching, the joint bars are straightened. Residual stresses are likely to develop at this point or during quenching. When dropped in the quench tank, joint bars have the potential to bend in the direction of least resistance. Residual stresses up to 20 ksi, tensile at the bottom and compressive on top, have been measured in joint bars (Figure 3).

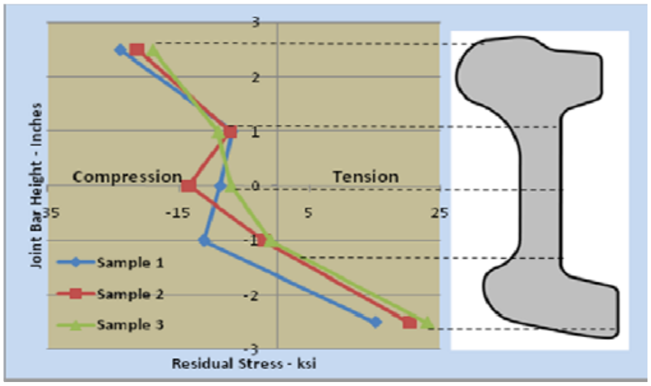

Figure 3. Residual stresses along cross-section in production joint bars

Test Matrix

Eighteen production (ready to be installed) 6-hole joint bars were acquired to evaluate residual stress relieving and stress reversal methods. All the joint bars were heated at a uniform temperature of 1150°F for 1.5 hours. Then they were divided into three groups of six bars. Each group was cooled using one of the following methods:

- Method 1 — Air cooling to room temperature
- Method 2 — Full joint bar water quenching
- Method 3 — Partial water quenching (Water quenching bottom half/air cool top half)

Method 3 was performed by dipping bars in 2-inch-deep water. The water level was kept constant during quenching to compensate for evaporation. Oil was not used to avoid the potential fire hazard during partial quenching. In order to reduce distortion, joint bars were laid on one side during full water quenching.

All joint bars treated with the three methods listed above were strain gaged and saw cut. Figure 4 shows the average residual stresses measured from each group of treated joint bars.

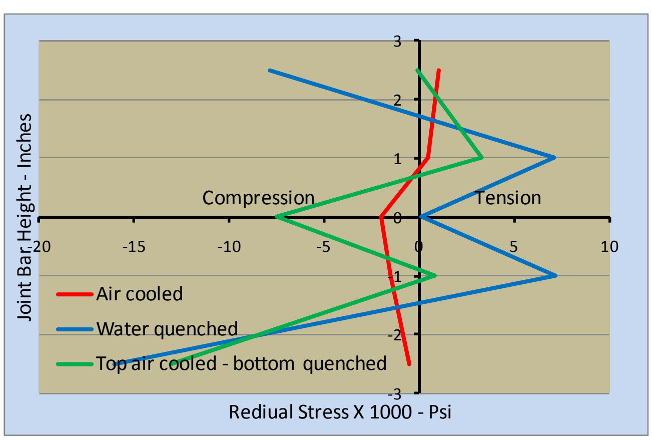

Figure 4. Residual stresses in joint bars induced during different stress relief methods

Figure 5 shows total stresses, which were calculated using the measured residual stresses for each method and previously measured bending and longitudinal stresses, 20,000 and 15,000 psi, respectively.

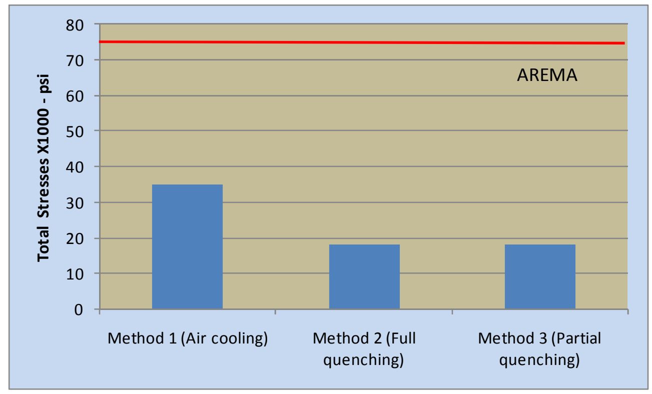

Figure 5. Total stresses in the bottom of joint bars

Joint Bar Distortions

Due to unequal cross-section areas on top, bottom, and sideways (i.e., no vertical or horizontal axes of symmetry), joint bars have a tendency to distort during the cooling process. Figure 6 shows plots of measured joint bar distortion after stress-relief methods were applied to the three groups of bars. The figure also shows a sample of the distortion measurements of production bars.

American Railway Engineering and Maintenance of Way Association recommends a maximum crown of 0.06 inch and a dip of 0 inch on the joint bar top. A crown of 0.04 inch is allowed on the joint bar side. Figure 6 shows that the crown on top of the production joint bars is within the recommended guidelines, but the crown on the joint bar sides is not. Different cooling methods applied for stress relief show the same results.

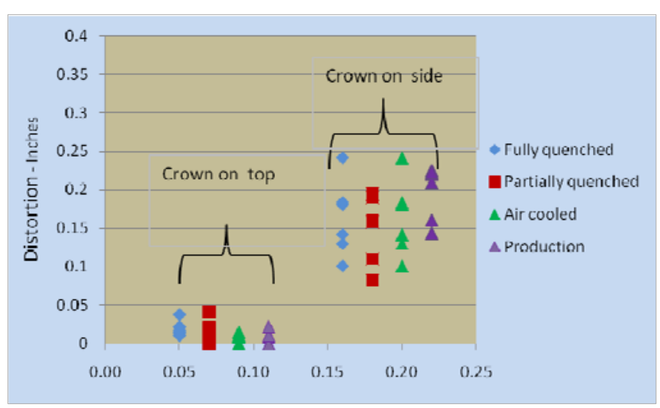

Figure 6. Measured joint bar distortions

Discussion

Test results have shown that residual stress management has excellent potential to be an effective way of increasing the service life of joint bars, as compared to increasing material strength or using larger cross sections.

Proposed methods to manage residual stresses do not require significant changes to current manufacturing processes. They may also be applicable to joint bars reclaimed from service.

Three cooling methods were applied to test joint bars heated to 1150°F for 1.5 hours. All three methods can reduce the service load stresses significantly, as Figure 5 shows. Method 1, air cooling to room temperature, showed the least benefit. Method 2, full joint bar water quenching, and Method 3, water quenching the bottom half and air cooling the top half of the joint bar, showed the highest benefits in terms of reducing the total stresses in joint bars.

External loads cause compressive bending stresses on the tops of joint bars. Also, railhead contact induces very high compressive stresses. These combined stresses exceed the material yield strength, which is evident from metal flow on top of the joint bar. Method 2 is likely to increase the metal flow due to introduction of compression. But Method 3 is likely to reduce overall compressive stresses on top of the joint bar, thus, reducing or eliminating metal flow.

Distortion on the top and sides of these joint bars was similar to distortion observed on production joint bars.

Future Work

Laboratory tests have been planned to quantify the extent of actual improvements in fatigue and crack growth of joint bars. Also, the effects of installation practices and service loads on joints will be measured nondestructively.

References

1. Akhtar, Muhammad N., and David D. Davis. August 2010. "Joint Bar Fatigue and Crack Growth Analysis," *Technology Digest* TD-10-024, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
2. Prevey, P.S., N. Jayaraman, and R. Ravindranath. June 2004. "Introduction of residual stresses to enhance fatigue performance in the initial design," *ASME Proceedings of Turbo Expo 2004*, Vienna, Austria.
3. Akhtar, Muhammad N., David D. Davis, and David Read. July 2010. "Load Environment of Standard Rail Joint Bars used in 39-ton Axle Load Service," *Technology Digest* TD-10-019, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.