TECHOLOGY DIGEST

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Bending Fatigue Properties of Rail Welds

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Summary

Recent laboratory studies show that the bending fatigue performance of wide-gap thermite welds was superior to the performance of standard thermite welds. In addition, from a limited number of test specimens, gas pressure rail welds exhibited excellent bending fatigue resistance in the tests and were superior to the standard electric flash-butt (EFB) welds.

Using a newly developed bending fatigue test procedure that evaluates the bending fatigue performance of rail and welded rails, Transportation Technology Center, Inc. has tested plain rails, standard thermite rail welds, and standard EFB welds. Results are being used as benchmarks for comparison with newly developed rail welds.

Bending fatigue resistance of rail and rail welds is important for the safety of railroad operations. Increased axle loads pose a greater challenge to the bending fatigue performance of rail, especially the bending fatigue performance of rail welds.

The fatigue resistance of a rail weld is affected by a number of factors including the strength of the weld, weld integrity, weld geometry, surface finish, and residual stress.

Suggested Distribution:

- ☐ Maintenance of Way
- ☐ Planning & Analysis
- ☐ Track Maintenance
- ☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads

INTRODUCTION AND CONCLUSIONS

When a train runs on track, the rail base bears cyclic tensile stresses. When the frequency of higher axle loads increase, the high cyclic stresses in the rail base make superior fatigue resistance for rail and rail welds more useful. To evaluate the rail-base fatigue resistance of rail welds, TTCI has developed a full-scale test procedure. The Bending Fatigue Test was designed to compare the bending fatigue performances of welds made using newly developed processes with those made using standard processes.

Plain rails, standard thermite rail welds, and standard electric flash rail welds were tested, and the results are being used as benchmarks for comparison with newly developed rail welds.

The bending fatigue performances of gas pressure welds and wide-gap thermite welds were superior to the benchmark welds. Some other modified thermite welds, electro-magnetic stirred thermite welds, and a 2-inch gap thermite weld did not compare favorably with the benchmark welds. Additional rail welds are being evaluated continually.

The Bending Fatigue Test

The Bending Fatigue Test is a full-scale laboratory test that evaluates the fatigue performance of rail and rail welds. In test, the rail or rail welds (4 feet or longer) is supported on two swivel points for an outer span of 39 inches. Downward cyclic loads are applied at two loading points on the railhead. The two loading points are spaced 6 inches apart and centered above the weld. A minimum downward load of 5 kips is used to keep the rail in a stable position. Maximum loads vary for each weld to obtain the stress — fatigue life relationship. The rail base is always in tension during the test. To complete the test within a reasonable timeframe, the cycling frequency is set at 5 Hz or higher. Figure 1 is a sketch of the test setup.

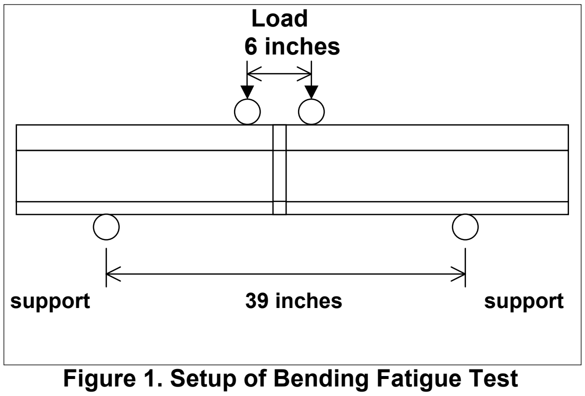

Figure 1. Setup of Bending Fatigue Test

In railroad service, rails made with state-of-the-art steel-making technologies are expected to last about 1,200 MGT in tangent track, which translates to more than 30 million wheel passes or bending cycles. Ideally, rail welds can last the entire rail life and endure the same number of bending cycles. However, it would be very costly and time-consuming to test rail welds to the cycles of actual service conditions.

Higher stress levels were used in the bending fatigue tests to ensure completion within two million cycles. The test provides a valid comparison of bending fatigue performance in service conditions as long as the test does not fall in the low-cycle fatigue range (less than 10,000 cycles).

Bending fatigue tests of rail welds are also being conducted in the laboratories at the University of Illinois/Urbana-Champaign and at Texas A&M University.

Major Factors Affecting Bending Fatigue Properties

The fatigue resistance of a rail weld is affected by a number of factors. The strength of the weld, weld integrity, weld geometry, surface finish, and residual stresses are among the major factors in determining the ability to resist bending fatigue. In general, the higher the strength of the weld metal and its heat affected zones, the better fatigue resistance of the rail welds. The bending fatigue resistance of a rail weld can be seriously reduced by the introduction of a stress raiser, such as a surface or subsurface weld defect, in the rail base. Sharp corners and rough surface may also cause stress concentration and reduce the fatigue resistance.

The stress in the rail base is a combination of bending stress in tension and residual stress. When compressive residual stresses exist in the rail base, the magnitude of the bending stress is reduced, and the fatigue life of the rail weld can be prolonged.

TEST RESULTS

Since the procedure for the Bending Fatigue Test was developed in 1998, TTCI has tested various rail welds and plain rails (without weld)..

Standard Thermite Rail Welds

With its easy portability, low-capital investment, and suitability for the conditions in the field, thermite rail welds are widely used in North America to join rails in the field and to repair rail or weld defects. But the mechanical properties of thermite welds normally do not equal those of rail steel. Further, thermite welds do not equal plain rail in terms of other fatigue influencing factors such as existence of material defects, geometry, and surface roughness. However, there is one important exception in residual stresses. TTCI has found that significant compressive residual stresses exist in the rail base of thermite welds. The determined residual stress of about -50 ksi is significant compared to the calculated maximum tension bending stress (60-90 ksi) and should be beneficial to the bending fatigue performance of thermite welds.

Figure 2 shows the bending fatigue performance of standard thermite welds (Std TW), with the performance of electric flash rail welds (Std EFW), and the rail itself. The performance of the standard thermite welds was inferior to that of the rail, despite the existence of beneficial residual stresses. The weld metal properties, weld geometry, and weld surface conditions are believed to be among the causes of the inferior performance.

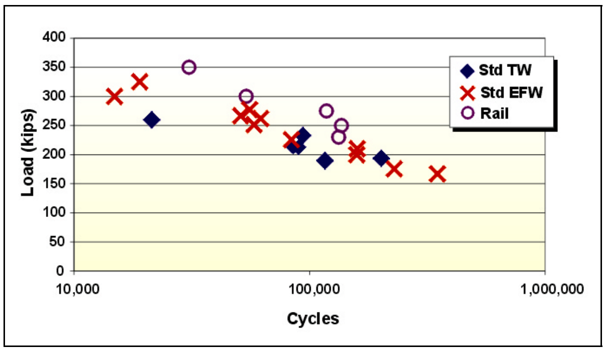

Figure 2. Bending Fatigue Properties of Standard Thermite Welds, Standard Electric Flash Welds, and Plain Rail

Standard Electric Flash Rail Welds

Electric flash welding is typically used in fixed rail welding plants, and its failure rate is low compared to that of standard thermite welds. In addition, mobile electric flash welding is used for in-track welding and applications in joint elimination, yard reinstallation, and continuous welded rail renewal. The welds used for bending fatigue tests were produced at a fixed plant using standard and head hardened rails. Since there was no significant difference between the bending fatigue performance of the welds made of standard rail and head hardened rail, the results were combined to represent electric flash welds in Figure 2.

The results of standard thermite welds, standard electric flash welds, and plain rail have been used as benchmarks to evaluate other types of rail welds. All rail welds tested were made using 136RE rail sections for valid comparisons.

Wide-Gap Thermite Rail Welds

Wide-gap thermite welds were developed for rail or weld defect repair and offer significant cost savings compared to current processes in which a rail plug and two standard thermite welds are used. Because of their extra width (2 3/4″), wide-gap welds can be used to directly replace defective field welds and other types of transverse rail defects. The bending fatigue performance of wide-gap thermite welds was superior to the performance of the standard thermite welds (Figure 3).

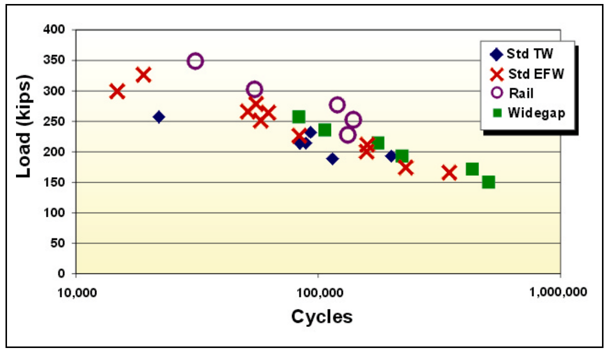

Figure 3. Bending Fatigue Performance of Wide-Gap Thermite Welds

Gas Pressure Rail Welds

From the 1930's to the 1970's, gas pressure welding to join rails was used extensively in North America. But with the onset of increased higher axle load cycles, the rate of weld failure increased and electric flash welding became the preferred process. Recently, however, TTCI has identified gas pressure welding as a potential alternative process for rail welding in North America because the process has been improved and successfully used in Japan. TTCI has conducted a series of laboratory tests including bending fatigue tests, and the gas pressure rail welds performed well in all laboratory tests.

Two gas pressure rail welds were tested for a maximum load of 160 and 180 kips, respectively. Both welds sustained more than 2,000,000 cycles without failure. The two welds were retested at a higher maximum load of 207 kips. One specimen fractured from base metal, not the weld, at 214,054 cycles. The other re-tested gas pressure weld endured another 2,000,000 cycles at the higher maximum load without failure. Figure 4 illustrates the relative bending fatigue performance of gas pressure rail welds. Note that the gas pressure welds did not fail in the test with the exception of the fracture in the base metal (rail). In this test, gas pressure welds exhibited better fatigue resistance than any other type of rail weld tested.

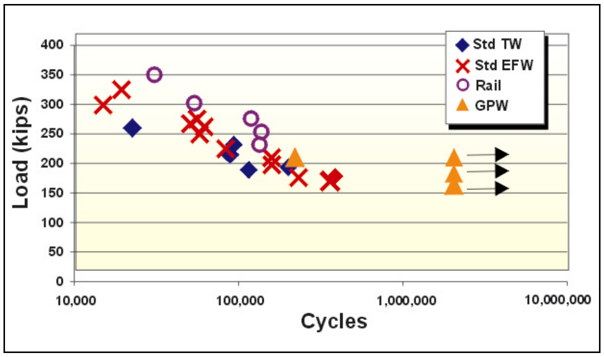

Figure 4. Bending Fatigue Performance of Gas Pressure Rail Welds

Other Rail Welds Tested or In Testing

In previous efforts to improve the performance of thermite rail welds, TTCI used electro-magnetic stirring technology in the thermite welding process. Although refined weld metal metallurgical structure was achieved, the bending fatigue performance of the modified thermite welds was actually worse than that of standard thermite welds, as Figure 5 shows. The attempt of using electro-magnetic stirring to improve thermite welding was deemed unsuccessful, partly from the unsatisfactory bending fatigue results.

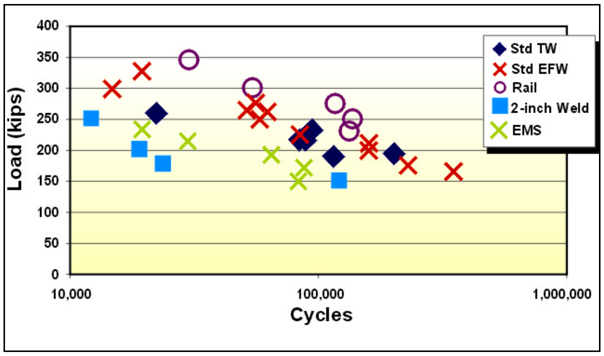

Figure 5. Bending fatigue Performance of Electro-Magnetic Stirred Thermite Welds and 2-Inch Gap Premium Thermite Welds

TTCI also tested 2-inch gap thermite welds developed for the defect repair of head hardened rails. The results were unsatisfactory (Figure 5).

TTCI is currently testing mobile electric flash rail welds produced with a modified procedure in which less rail is consumed. TTCI also plans to test the products from a new thermite welding supplier. The products include standard and wide-gap thermite welds with smoother weld contours in the rail base and a new type of rail weld — "head hardened" thermite welds.

DISCUSSION AND FUTURE WORK

Bending fatigue resistance of rail and rail welds is important for the safety and efficiency of railroad operations. The increased numbers of high axle load cycles in recent years pose a greater challenge to the bending fatigue performance of rail and particularly the bending fatigue performance of rail welds. Currently available rail defect detection technology has not been very effective in detecting fatigue cracks in the rail base, and the search for better methods to address this matter further strengthens the importance of bending fatigue resistance of rail and rail welds.

The Bending Fatigue Test was developed to address the important nature of rail and rail weld performance. It has been a useful tool in developing new technologies to meet the challenges of increased axle loads.

This test is relatively new and its resultant database will improve when more new rail welding products are developed and tested. Eventually, it may become a candidate for standard rail weld test procedures serving the railroad industry.

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