TECHNOLOGY DIGEST

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Fatigue Bending Test of Thermite Rail Welds

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Summary

A full-scale rail bend fatigue method for testing rail and rail welds has been successfully developed by Transportation Technology Center, Inc. for the Association of American Railroads. The test, based on four-point loading, was designed to compare thermite welds made with a newly developed process with ones made with a standard process. In the tests, the rail base was in tension when stressed. However, the test can be done with the head in tension if required. The thermite rail welds tested include wide-gap welds, standard 1-inch gap welds, and 1-inch thermite welds made with electromagnetic stirring (EMS). Test results show that:

- Wide-gap welds (68 mm, ~2 ¾ inches) constantly exhibited longer fatigue life than the 1-inch standard welds.
- EMS welds had a shorter fatigue life than standard welds.

All the welds were made with 136RE standard carbon rail using the Railtech QP CJ "one-shot" process. The standard thermite welds are one-inch gap welds presently used in North American railroads. The wide-gap thermite welds have an initial gap of ~2 ¾ inches and offer potentially significant savings for the repair of defective welds or rails. The EMS welds tested had a special configuration and this may have affected their performance in the tests.

The minimum load was kept at 5 kips for all tests while the maximum loads varied to obtain the stress fatigue life relationship. All the tests were conducted at cycling frequencies in the range of 3 Hz to 5 Hz. A strain gage was mounted at the center of the rail base bottom as a check on the repeatability of load application.

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

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INTRODUCTION

Slow bending tests and rolling load tests have been the major full-scale rail or rail weldment tests used by North American railroads to characterize weld performance. The slow bend test is simple, cost effective, and can be completed in a very short time. The rolling load test is a full-scale fatigue test with the load applied on the railhead through rolling contact. In this test the railhead is subjected both to rolling contact and tensile load; failures are mostly developed from the head or upper part of the web. While both tests have their advantages, they also have certain limitations. Neither test can determine the fatigue performance of the rail base where cyclic bending tension stress occurs when a train passes. An alternative full-scale test to determine the bend fatigue strength of the rail base is needed for that purpose. The present fatigue test has been developed to assess the bending fatigue strength of welds.

Three types of thermite rail welds were tested with the newly developed fatigue test. The welds are :

- Standard 1-inch gap welds, the primary thermite welds used in North American railroads.
- Wide-gap (~2 ¾-inch) welds, developed for rail or weld defect repair.
- EMS welds, standard-gap thermite welds made with application of electromagnetic stirring (EMS) during solidification to improve metal structure.

Laboratory tests show that the wide-gap welds are very similar to the standard welds in most properties, but have a slightly lower rupture modulus and deflection in the slow bending test (TTCI TD 98-026). With the present fatigue test, this concern of the wide-gap weld's lesser performance in slow bend tests is addressed.

The test is relatively new and there is no previous database to benchmark the test results. As test results accumulate, it is intended that the database will develop to serve as a body of weld performance data against which new welding methods can be judged. In addition to tests of thermite rail welds, tests of electric flash butt rail welds and plain rail itself will be very helpful in interpreting the fatigue performance of improved or new rail welding methods.

THE BEND FATIGUE TEST

The test setup is shown in Exhibit 1. The rail (approximately 4 feet in length) is supported on two swivel points to give an outer span of 39 inches. Loads are applied by two hydraulic actuators spaced at 6 inches and centered above the weld. These actuators can apply a downward load to the test rail but not an upward load. Thus a minimum downward load of 5 kips was used for all tests to keep the rail in a stable position. The maximum loads varied for each weld to obtain the stress fatigue life relationship. All the tests were performed at cycling frequencies below 10 Hz and most of the tests were conducted at 5 Hz to give a constant repeating maximum stress. A strain gage was mounted at the center of the rail base bottom as a check on the repeatability of load application.

The test was set up to be very similar to that of the standard rail fatigue test in Europe.This was done so that eventual use can be made of rail and rail weld fatigue data produced in Europe. Strain gage measurements indicate that the stresses at the weld and the adjacent area, including the heat-affected zones, are somewhere between the calculated stresses of four-point bend and three-point bend conditions. This is most probably because

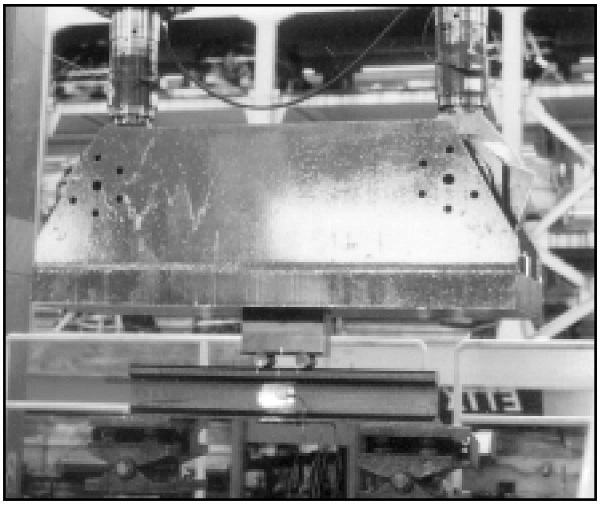

Exhibit 1. Rail Bend Fatigue Test Fixture. A rail with Strain Gages is in Place for Calibration

the inner loading span (6 inch) is relatively low compared to the depth of 136-RE section rail (7 5/16 inch). For that reason it is sometimes called a “three-and-half-point” bend test.

In Europe, the standard for thermite rail welds requires a maximum stress of 32 ksi (220 MPa) and a minimum stress of 7.25 ksi (50 MPa) to be applied on the rail base. A minimum of 2 million load cycles without failure is required. In the TTCI tests, load is used as a parameter instead of the stress because load reading has proved to be more reliable than reading from the strain gage on the rail base. A strain gage, however, was mounted at the center of the base in every test weld to verify the load setting. In most cases, the reading from the strain gage was compatible with the load reading for the initial cycles but gradually decreased during the test, probably because of the deterioration of the bond between the gage and the rail. The applied maximum loads, and therefore the maximum stresses, were set much higher (up to 87-102 ksi, 600-700 MPa) than that in the European test to accelerate the tests and to account for heavier North American axle loads. The tests were conducted at different maximum load levels to obtain the load-cycle relationship for each type of weld.

THE WELDS

The welds tested include six standard 1-inch gap thermite weld, six wide-gap thermite welds, and five electromagnetic stirring (EMS) treated thermite welds as indicated in Exhibit 2.

Standard thermite welds are widely used in North American railroads to join rails in the field and to repair rail or weld defects. These welds represent the vast majority of the thermite welds in North American service.

Weld type	Gap (inch)	EMS	Specimens
Standard	1	no	6
Wide-gap	2.5	no	6
EMS	1	yes	5

Exhibit 2. Welds Tested under the Bend Fatigue Test Fixture

Wide-gap thermite welding was developed to provide an alternative process for rail or weld defect repair and can potentially offer significant cost savings compare to current weld repair processes (TTCI TD 98-026). Because of their extra width, wide-gap welds can be used to directly replace most defective field welds and other types of transverse rail defects.

The EMS thermite welds are made with electromagnetic stirring of the weld metal during the solidification process. This process refines the weld metal’s solidification microstructure and is intended to improve mechanical properties.

All the welds were made with 136RE standard carbon rails and the Railtech QP-CJ “one-shot” process. To ensure a representative and constant quality of the test welds, all the welds were made by the thermite welding suppliers. The standard welds and wide-gap welds were made by Railtech Boutet of the United States. EMS welds were made by Railwel of Canada with the cooperation of the Canada Center for Mineral and Energy Technology (CANMET) who developed the EMS thermite welding process under a contract with TTCI.

The EMS welds were made with short rail pieces (< 7 inches in length) due to the limitation of the EMS apparatus. The welds were extended for rail fatigue testing by joining (with thermite welding) additional rail at both ends. The three-weld configuration may alter the residual stress condition of the test weld. Additionally, the alignment of such a completed weldment is difficult to ensure.

TEST RESULTS AND DISCUSSION

Fracture toughness of thermite weld metal is usually very low. In rail bending fatigue tests, once small cracks develop in the rail base, it may take only a few cycles for the rail to fracture under the high tensile stress. Therefore, crack propagation is not studied in the test and all welds were tested until fracture. Test results are as shown in Exhibit 3.

As expected, fractures started from the base area either at the edge of the weld collar or at the center of the weld. The wide-gap thermite welds showed better performance than the standard

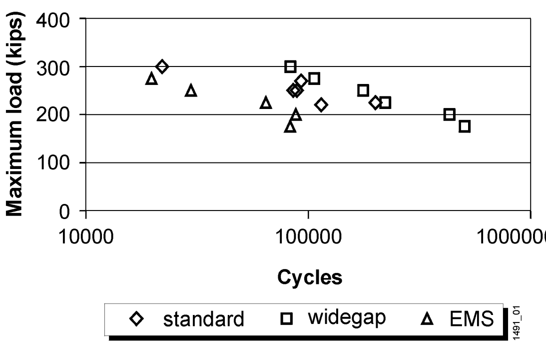

Exhibit 3. Results of Bend Fatigue Testing of Thermite Welds

welds, with less scatter. However, the sample size for both types of weld was relatively small (6 welds) and further testing would be needed to establish the statistical significance of the improvement. It is clear, however, that the EMS welds gave poorer performance than the standard and wide-gap welds.

The wide-gap welds and standard welds exhibited similar mechanical properties in other laboratory tests such as tensile, hardness, slow bend, rolling load, etc. (TTCI TD 98-026). Thus it was expected that the wide-gap welds would perform as good as the standard welds. Analysis of the surface finishing and geometry of the wide-gap welds did not reveal any significant difference from those of standard welds. A preliminary stress calculation indicates that the maximum tension at the edge of the weld collar of the wide-gap weld is marginally lower than that of the standard welds. This is because true 4-point loading conditions are not achieved in the test. The weld metals of both types of welds were analyzed for their contents of inclusion and porosity. Results show that weld metal of wide-gap welds is somewhat cleaner than that of standard welds. The cleaner weld metal of wide-gap welds may be due to the longer solidification time (that allows for increased flotation), but the effect of this on performance is not known.

Earlier laboratory tests have demonstrated that EMS breaks up the normal cast dendritic microstructure seen in thermite welds, producing a more equiaxed grain structure. However, EMS has not been shown to produce a consequent improvement in strength or ductitility. Equally, EMS has not been shown to reduce the level of porosity and may in some cases increase pore size. The bend fatigue test results do not provide much encouragement for further development on this technology. At the same time, the contractor for design and manufacture of an EMS coil for field rail welding concluded that, in order to obtain sufficient stirring effect in the weld metal, either a crane is needed to operate a very massive coil or the current thermite mold would have to be significantly altered to accommodate the EMS coil. Neither option is practical. Therefore the investigation of EMS effect in improving thermite weld performance has been suspended.

FUTURE TESTS

Rail bend fatigue testing examines the rail base fatigue strength of rail and rail welds. Like other laboratory testing, a database is needed to establish a criterion for judging the performance of improved welds. Additional tests are planned for electric flash butt rail welds, premium thermite welds (both standard and wide-gap), and rails without welds. A more comprehensive database will be available when those tests are completed.

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