TECHOLOGY DIGEST

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LABORATORY EVALUATION OF WIDE-GAP THERMITE RAIL WELDS

by Jian Sun and Kevin Sawley

Summary

Laboratory tests undertaken by Transportation Technology Center, Inc., show that wide-gap (68 mm, 2.68 inches) welds have properties very similar to conventional welds and are fit for service trials. The welds, which can be used to directly replace most defective welds (and possibly other types of rail defects), have properties very similar to those found in standard (1-inch gap) welds. Tests show that:

- Wide-gap welds take about 6 minutes longer to make than standard welds, because of extra solidification time needed.
- In metallurgical structure and mechanical properties, wide-gap welds differ little from standard welds.
- As with standard welds, wide-gap welds have beneficial residual stress in the rail foot, which helps protect the weld against fatigue.
- The bend-test properties of wide-gap welds are marginally lower than standard welds, but the measured modulus of rupture exceeds the minimum specified for plant welds.

Both types of welds were made in 136RE standard rail, using the Railtech Boutet QP CJ "one-shot" process. Because of their extra width, wide-gap welds can be used to directly replace most defective field welds, and possibly other types of rail defects, at significant cost savings. At present, rail defects are repaired using two welds and a plug rail. In addition to offering reduced repair cost, wide-gap welds will lower track-occupancy time, and reduce the number of welds in track, thereby increasing the potential for safety. Current studies are examining their performance in track, and in full-scale fatigue loading. Future work will determine how they can be used to best advantage in service.

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

To gain assurance that they can be used with confidence in North American service, Transportation Technology Center, Inc. (TTCI), has evaluated wide-gap (68 mm, 2.68 inches) thermite welds and compared them with standard (1-inch) gap welds. Both types of test welds were made in 136RE standard rail, using the Boutet QP CJ "one-shot" process. Laboratory tests to evaluate the welds show:

- Wide-gap welds take about 6 minutes longer to make, because of the extra solidification time needed.
- Wide-gap welds exhibited inclusion levels similar to standard welds.
- In structure, residual stress, and mechanical properties (including slow bend), wide-gap welds differ little from standard welds.

Because of their extra width, wide-gap welds can be used to directly replace most defective field welds, and other types of rail defects, at significant cost savings. At present, rail defects are repaired using two welds and a plug rail. Wide-gap welds offer reduced cost, lower track-occupancy time, and increased safety by reducing the number of welds in track. Further studies are under way to examine their performance in track, and in fatigue loading, and will evaluate how they can be used to best advantage in service.

MANUFACTURE OF TEST WELDS

Wide-gap and standard thermite welds were made using new 136RE standard rail. Welds were made by Railtech Contracting Corporation using the Boutet QP CJ "one shot" process in a railroad yard fixture at Cleveland Track Material (Chicago). The fixture was used for good alignment, and to ensure that test welds were produced under reasonably typical railroad conditions. In all, 34 welds were made — 19 wide gap and 15 standard (1-inch gap). A conventional oxygen-propane preheating system was used, with a nominal 6.25 minutes preheating time for both welds. Actual preheating time and tap times for each weld were recorded, as well as time to subsequent actions. These are shown in Exhibit 1.

	Welds	
	Wide-gap	**Standard**
Preheat time (sec)	392±8.5	386±8.6
Tap time (sec)	All within limits	
Actions (minutes after tapping)		
Slag-pan removal	3	3
Crucible removal	3.5	3.25
Clamp/jacket removal	10	4
Shearing	11.5	6

Exhibit 1. Details of Weld Manufacture

There is no difference in time needed to set up wide-gap and standard-weld mold assemblies. Thus, wide-gap welds are likely to increase total welding time by about 5 to 6 minutes. This extra time is needed so that the greater mass of molten metal can solidify before shearing. As is the case with any thermite weld, early use of shears will lead to damaging hot tears in the railhead. (There may be a further small increase in overall weld time because of increased railhead grinding needed for wide-gap welds.)

LABORATORY TESTS AND RESULTS

Rolling-load test

Three wide-gap welds were tested in rolling-load machines according to standard TTCI procedures. In all cases the load applied to the railhead top was 59,400 pounds. Two welds passed the criterion of 2 million cycles without failure. The third weld failed at 1.6 million cycles from small defects at the collar edge at the center of the web.

Slow-Bending Test

Three wide-gap and three standard welds were tested at Miner Enterprises (Chicago) according to American Railway Engineering and Maintenance of Way Association (AREMA) four-point slow-bend test procedures. Exhibit 2 details the results.

Wide-gap welds showed slightly lower strength (by 3 percent) and deflection properties (by 13 percent). Thermite welding standards are being examined by the industry, but there is no current slow-bend test standard. For comparison, for plant welds the AREMA specifies a minimum deflection of 1 inch, and a minimum modulus of

120,000 pounds for standard rail under four-point loading. All the welds in Exhibit 2 exceed the draft European thermite specification, which effectively calls for a minimum modulus of 108,000 pounds and does not require a minimum deflection.

Welds	Maximum load (kips)	Deflection (inch)	Modulus of rupture (ksi)
Wide-gap: 1	407.0	0.712	129.4
2	431.6	0.926	137.3
3	443.3	0.982	141.0
Average	**427.4**	**0.873**	**135.9**
Standard: 1	446.2	1.037	141.9
2	424.4	0.910	135.0
3	448.5	1.049	142.7
Average	**439.7**	**0.999**	**139.8**

Exhibit 2. Results of Slow-Bending Tests

Structure, Shape, and Ultrasonic Testing

Macrostructure specimens were taken to reveal the weld cross-section along the rail longitudinal center line. The wide-gap and standard weld specimens showed complete fusion between the weld metal and the rail ends. However, the amount of rail end melted in the base of the wide-gap weld was barely adequate (0.078 inch). Such minimal melting implies that minor changes in the weld installation may lead to lack of fusion defects. To overcome this, the weld manufacturers suggested modifying the position of the preheating torch. A further weld made with a repositioned torch showed fully acceptable rail-end melting, with a minimum melting of 0.22 inch on both sides of the weld. Railtech Boutet has adopted this torch repositioning in its wide-gap weld procedure.

The width of the heat-affected zone (HAZ) of wide-gap welds was similar to that of standard welds. This is important, since HAZs are softer than parent rail, and wear at a greater rate. Wider zones are thus likely to give greater weld dip, greater dynamic forces, and shorter weld life. HAZs are unlikely to present a special problem with wide-gap welds. The metallurgical structures of the weld metal in wide-gap and standard welds was very similar at both the micro- and macrolevels. There was no significant difference between the welds in terms of size and density of porosity and inclusions. Both types of welds had smooth transitions between the weld collars and the parent rails, and no sharp corners. Neither weld showed evidence of severe stress concentrations that might impair performance.

All welds (standard and wide gap) were examined ultrasonically using 0-, 45-, and 70-degree probes from the rail top. No defects were found. In addition, two wide-gap and two standard weld samples were cut to a length of 12 inches with the weld central. These were examined from the rail ends with a 0-degree probe, and no defect indications were found. The implication is that, when properly made, wide-gap welds should have no greater defect levels than standard welds.

Tensile Properties, Hardness, and Chemical Composition

Tensile specimens were taken longitudinally from the base and head of wide-gap and standard welds. In all cases the specimens were taken with the fusion line at the center of the gage length. All fractures occurred outside the gage length, but results consistently showed that the wide-gap welds had similar strength and ductility to the standard welds.

Internal hardness traverses were made 5/8 inches below the running surface, using a Rockwell C tester. The hardness profiles across the two types of weld were similar (Exhibit 3). Results confirmed that wide-gap welds do not have exten-

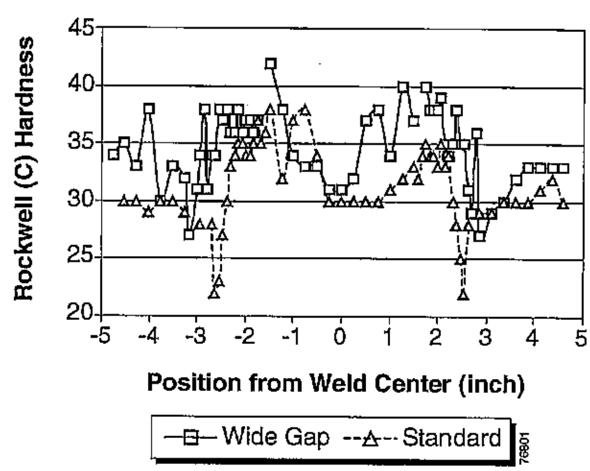

Exhibit 3. Hardness Profiles across Standard and Wide-Gap Welds

sive HAZs. Measurements of surface hardness, and internal hardness in the rail base, reaffirmed the above finding.

Chemical analysis showed that, with the exception of vanadium (higher in the wide-gap weld), and manganese (lower), the chemistries of both types of welds were similar. Vanadium is likely to increase strength, and may balance the slightly lower manganese content of the wide-gap weld.

Both welds had lower carbon content than the parent rail weld (about 0.64 percent, compared to 0.74 percent). However, they had higher silicon content, which may compensate for the lower carbon content and also may increase strength.

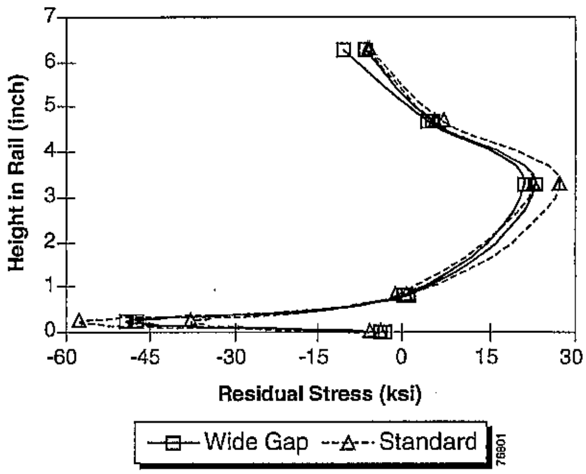

Exhibit 4. Measured Residual Stresses in Thermite Welds

Residual Stress

Residual stresses formed in manufacture have a large effect on the service life of welds. Normal welds have compressive residual stresses at the bottom of the rail foot, which protect against fatigue. Because of this, the strain-gage technique was used to measure residual stress in both types of welds. Gages attached to the surfaces of the welds at the collar-to-rail interface, measured longitudinal stress in the head, web, and base. Two welds of each type were examined. Results in Exhibit 4 show that wide-gap welds have stresses no different from standard welds.

DISCUSSION AND FUTURE TESTS

The properties of wide-gap welds are very similar to those in standard welds. The third wide-gap weld in the rolling-load test did not pass 2 million cycles. However, failure was from a defect which can also occur infrequently in standard welds. Further tests of wide-gap welds are under way. Their long-term performance is being monitored in track at the Facility for Accelerated Service Testing. Also, a full-scale fatigue fixture has been built to test welds in four-point loading. Tests will be completed later this year.

Wide-gap welds take about 6 minutes longer to make, but allow defective field welds and possibly other rail defects to be repaired using one weld, instead of two standard welds and a 20-foot rail plug. Wide-gap welds can also provide additional time-savings since it usually takes less time to align existing rails to make a wide-gap weld than it takes to align a rail plug in the track. The final task of this project will be to define where, and under what conditions, these types of welds can be used to the best advantage.

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