

PERFORMANCE OF MANGANESE STEEL WELDS UNDER ROLLING-LOAD TESTS

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Summary

Studies were conducted to identify the best welding practices for increasing service life of repairs on frogs and crossings cast from austenitic-manganese steel (AMS). These investigations have demonstrated the effect of weld-metal composition and the importance of limiting heat input and controlling temperature during the welding process. In tests conducted by the Association of American Railroads at its Transportation Technology Center near Pueblo, Colorado, specimens were made by depositing weld metals on rail section castings of manganese steel using different materials, welding processes, and welding parameters. The specimens were then subjected to a series of rolling-load tests.

Major findings from the tests are:

- Although high-carbon weld metals made by flux-cored arc welding (FCAW) performed well in keeping their original geometry, they were less crack resistant than low-carbon welds under heavy axle load or impact load.
- Low-carbon weld metal made by shielded-metal arc welding (SMAW) showed better resistance to cracking, but less resistance to deformation (metal flow).
- Temperature control, which is achieved by limiting the width of weld bead as well as the interpass temperature, is necessary to prevent premature failure of the welds.

An estimated \$20 million is spent annually on weld repairs of frogs. These repairs help maintain a system that includes approximately 100,000 turnout frogs and 20,000 diamond frogs. In-track weld repair can extend the life of a frog, though the actual amount varies according to each frog. The average frog sees several weld repairs over its lifetime. Welding is done to replace metal (from wear and deformation) and to repair cracks that form due to fatigue.

SMAW and FCAW are the most widely used welding processes for AMS frog repairs among North American railroads. The service life of the weld repairs is usually significantly shorter than that of the original AMS casting. Subsequent cracking frequently originates from previous weld repairs or their heat-affected zones.



Suggested Distribution:

- Maintenance of Way
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INTRODUCTION AND CONCLUSIONS

The Association of American Railroads' austenitic-manganese steel (AMS) frog/crossing repair welding program has demonstrated through rolling-load tests the effect of weld-metal composition and the necessity of controlling the temperature during the welding process. Results show that although flux-cored arc welding (FCAW) weld metal with high carbon content has high initial hardness and performed well in keeping its original geometry, it is vulnerable to cracking, especially under impact load. Low-carbon weld metal made with shielded-metal arc welding (SMAW) showed better resistance to cracking, but less resistance to deformation (metal flow).

Shielded-metal arc welding (SMAW) and flux-cored arc welding (FCAW) are the most commonly used processes for manganese-steel frog and crossing repairs. The service life of weld repairs on AMS frogs or crossings varies over a large range and is usually shorter than that of the original casting. The AWS Recommended Practices D15.2 recommends a maximum interpass temperature of 500 degrees Fahrenheit and a 5/8-inch maximum bead width. Actual practice in the field can vary from these standards. The most common reason is the lack of track time available to make proper welds. Very little information is available on the performance difference of welds made using different welding practices.

The AAR's AMS frog/crossing repair weld-

ing program endeavors to provide information useful to member railroads in improving the service life of repair welds on AMS frogs and crossings. The effort includes study of weld metal and heat-affected zone properties, industry practice survey, laboratory rolling-load tests and field tests. This document reports the major findings from the laboratory rolling-load tests.

THE WELDMENTS

Test weldments were prepared by depositing weld metal on the head of 136RE cast AMS rails. The rails were cast with the same chemistry and procedure for AMS frogs in a major AMS frog supplier's foundry.

The AMS-type welding consumables used in the test include a flux-cored wire with higher carbon content, and an electrode with a lower carbon content. Both are widely used in railroad frog repair. Exhibit 1 lists the chemical compositions of deposited weld metal. An independent analysis was conducted on the testing specimens after rolling-load tests. The samples were taken away from weld metal distant from weld fusion lines to minimize the dilution effect.

Weld deposits were made with different welding parameters, welding practices and deposit thicknesses as illustrated in Exhibit 2. The "standard" practice represents the heat-control practice recommended in AWS D15.2. In "cautious" welding practice the heat input and interpass temperatures were kept much lower than what is allowed in AWS D15.2, while in

Exhibit 1. Chemical Composition of Deposited Weld Metals

Consumable	Electrode for SMAW		Flux cored wire for FCAW	
	Nominal Composition	Actual Composition	Nominal Composition	Actual Composition
C	0.56	0.53	0.80	1.02
Mn	16.88	15.9	22.0	17.0
Ni	3.90	9.33	0.80	6.22
Cr	-	2.82	3.65	3.22
Mo	1.17	0.99	0.15	0.17
Si	0.06	0.22	0.40	0.25



Exhibit 2. Weld Specimens for Rolling-Load Tests

Rolling-Load Machine	Weld Thickness (inch)	Welding Process	SMAW			FCAW		
			Welding Materials	Low C Electrode			High C Flux-Cored Wire	
		Welding Practice	Cautious	Standard	Fast	Cautious	Standard	Fast
Cradle	1/8	Specimen		1	3		2	4
Cradle	3/8			5			6	
Long Stroke	3/8		9A	7A	8A	9C	7C	8C

"fast" welding practice the heat input and inter-pass temperature significantly exceeded the recommended limits.

ROLLING-LOAD TESTS

In rolling-load testing a wheel travels back and forth on top of the rail specimen to simulate the loading conditions in railroad track. Two types of rolling-load machines were used in the test: a cradle-type machine and a long-stroke machine.

In the cradle machine, the rail specimen in the cradle slowly tilts from a vertical position to a 1:5 cant position. Thus the loading path is narrow and always changing. It is a severe test for a weld's resistance to metal flow and subsurface

cracking. The wheel load was designed for 50 kips for the test, but increased to 65 kips to accelerate the testing.

In the long-stroke machine, "flangeway gaps" were machined on the running surface (top) of the rail-weld specimens. When the loading wheel passed over the gaps, impact load was applied on the edges. The "static" wheel load was set at 40 kips. Up to three welds were made on the running surface of each cast rail and the welds designated as A, B and C. One "flangeway gap" was made on each weld and was positioned in such a way that the wheel speed was the same when it traveled over the gap on weld A as that on weld C. The arrangement secures a

Exhibit 3. Rolling-Load Test Results of Weld Specimens

Weld	Welding Consumable	Welding Practice	Thickness (inches)	Wheel Load (kips)	Total Test Cycles	Crack Found between Cycles
1	Low C Electrode	Standard	1/8	50-60*	3,573,500+	3,573,500-3,922,200
2	High C Flux-Cored Wire	Standard	1/8	65	3,019,700	2,000,000-3,000,000
3	Low C Electrode	Fast	1/8	65	1,753,600	1,000,000-1,500,000
4	High C Flux-cored Wire	Fast	1/8	65	1,500,000	1,000,000-1,500,000
5	Low C Electrode	Standard	3/8	65	4,001,000	No Crack
6	High C Flux-Cored Wire	Standard	3/8	65	2,000,000	1,551,900-1,843,000
7A	Low C Electrode	Standard	3/8	40	2,000,000	No Crack
7C	High C Flux-Cored Wire	Standard	3/8	40	2,000,000	204,398-292,523
8A	Low C Electrode	Fast	3/8	40	526,703	No Crack
8C	High C Flux-Cored Wire	Fast	3/8	40	526,703	75,500-100,000
9A	Low C Electrode	Cautious	3/8	40	754,908	301,699-467,678
9C	High C Flux-Cored Wire	Cautious	3/8	40	754,908	301,699-467,678



valid comparison between results of weld A and weld C. Weld B on each cast rail was designed for other test objectives and these results will not be presented in this document.

In both machines the specimens were fully supported on the rail base for the entire wheel loading range. Tests were stopped periodically to measure the hardness and profile, and to observe crack initiation and propagation on the specimens.

SIGNIFICANT FINDINGS

Exhibit 3 shows a summary of the rolling-load test results. Weld 1 was tested in the cradle machine under 50 kips wheel load for more than 3.5 million cycles without significant failure. To accelerate the test, the wheel load was increased to 65 kips and kept at that level for the rest of the cradle-machine tests.

Because of the change of wheel load during testing, it is difficult to compare the results of Weld 1 to those of other specimens. Specimens 3 and 4, which had high heat input and high inter-pass temperatures, were the least resistant to cracking. They were also the least resistant to deformation as shown in Exhibit 4. Cross-section area loss at the running surface was chosen as the indicator of deformation and wear in Exhibit 4. The excessive welding heat probably damaged the substrate cast metal and affected the performance of the welds.

For the two thicker (3/8-inch) welds tested in the cradle machine (welds 5 and 6), the properties of the substrate casting were less influential, so the results are more representative for the performance of deposited weld metal. The higher-carbon weld metal (weld 6) made by FCAW performed much better in keeping its original geometry under the heavy wheel load than the lower-carbon specimen (weld 5) made by SMAW as shown in Exhibit 4. But the former is prone to cracking as shown in Exhibit 3 and it is

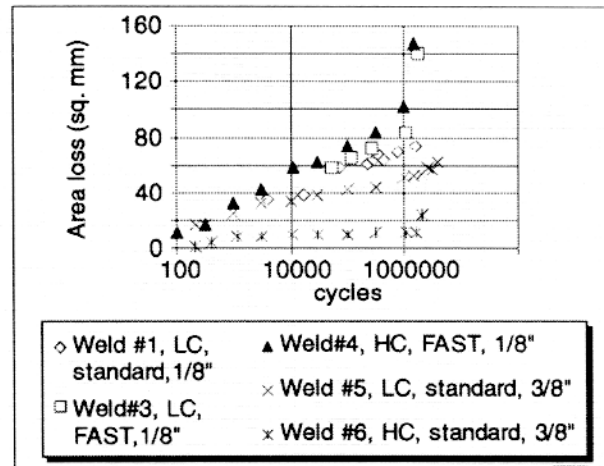


Exhibit 4. Cross-Section Area Loss on Rail Running Surfaces during Cradle-Type Rolling-Load Tests

probably due to its lower toughness discovered in an earlier study (reported in TD96-008). The high-carbon weld metal was also found to be less resistant to cracking under impact load when comparing welds 7A and 8A to welds 7C and 8C in Exhibit 3.

From results in Exhibit 3, it can be found that the welds made with "fast" welding practice performed consistently inferior to the corresponding welds made with "standard" welding practice. In making the "fast" welds, the limits in AWS D15.2 for heat input and temperature control were significantly exceeded. In the case of the "standard" welds the AWS D15.2 limits were followed. The results emphasize the importance of limiting the heat input and control of inter-pass temperature. Interestingly, Weld 9A, which was made with "cautious" welding practice and a low-carbon electrode did not perform as well as other low-carbon electrode welds in impact load tests. The cause for 9A's poor performance is unknown at this time.

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