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EVALUATION OF BAINITIC TEST RAILS

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Summary

A laboratory investigation of a 36-ton commercial cast of bainitic test rail, made to the J6 experimental composition, has determined that the rails are suitable for testing at the Facility for Accelerated Service Testing (FAST). The investigation concluded that the excellent properties found in the small experimental cast have been replicated in the commercial cast. Other main conclusions include:

- The bainitic test rails have higher hardness (430 hardness Brinell) than current premium rail steel (approximately 340 to 390 hardness Brinell), and higher strength.
- The bainitic microstructure is uniform, with no evidence of segregation. But it contains very small angular inclusions (probably nitrides). These are unlikely to pose a problem for trial rails; however, means to reduce their incidence should be sought for volume rail production.
- Strain-gage measurements and web saw-cutting measurements indicate that residual stresses in the roller-straightened bainitic rails are no higher than those found in typical premium rail.
- In laboratory wear tests intended to simulate dry gage-face wear at the high rail in 5-degree curves, the J6 test rails show the same type of severe wear as premium rails, but about one half the wear rate.

The J6 alloy is a high-strength experimental bainitic steel developed by the Association of American Railroads and the Oregon Graduate Institute to have better wear resistance than current premium (head-hardened) rail steels. The 36-ton cast of steel was produced by Ellwood City Forge, and rails (136-10 section) were rolled and roller-straightened by Pennsylvania Steel Technologies. The J6 rail does not need a head-hardening process, and this will offset its higher alloy cost over premium rail.

In 1998 three 80-foot lengths of J6 test rail will be installed in FAST Section 7 at the Federal Railroad Administration's Transportation Technology Center. Measurements made at intervals on all rails will characterize wear performance, which will be detailed in a future report.

Suggested Distribution:
☐ Maintenance of Way
☐ Maintenance Planning
☐ Track Maintenance
☐ Bridges and Roadway

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INTRODUCTION AND CONCLUSIONS

An investigation of experimental bainitic rails designed to have better wear properties than premium rail steel has concluded that the rails are acceptable for tests under heavy axle loads at the Facility for Accelerated Service Testing (FAST). Other conclusions are:

- With a Brinell hardness of approximately 430, the bainitic rail is substantially harder than head-hardened premium rail which rarely exceeds 390 Brinell.
- The bainitic rail has higher tensile and yield strength than premium rail.
- The bainitic steel appears inherently ductile. However, because of its high hardness, it is more notch-sensitive, and measured ductility varies between wide limits.
- The roller-straightened bainitic rail has a residual stress pattern different from that normally seen in rails, but the residual stresses are no higher than stresses measured in premium rail. The test rails meet the web saw-cut opening test proposed by the American Railway Engineering Association (AREA).
- In laboratory wear tests, bainitic rail samples have shown much less wear than premium rail samples tested under identical conditions.

The 136-10 section rails, made to the J6 chemistry developed by Oregon Graduate Institute (OGI) and the Association of American Railroads[1], were rolled by Pennsylvania Steel Technologies (PST). The steel was made in the electric furnace by Ellwood City Forge, vacuum-degassed, and ladle-refined. Wear-resistant premium rail is currently preferred for curved-track applications. Its good wear resistance is conferred by high head hardness derived from in-line heat treatment. Current premium rails appear to be nearing their limit of improvement, and bainitic steels have been developed with the objective of achieving a step increase in wear resistance.

MICROSTRUCTURE AND CLEANNESS

Eight 80-foot rails were produced by PST. One has been tested at the Federal Railroad Administration's Transportation Technology Center to ensure that the rails are acceptable for wear trials at FAST. The objective was to compare properties of the test rails with those found in the original experimental steel, and with typical head-hardened rail steel. Exhibit 1 shows the steel-makers were able to produce the large cast of steel (36 tons) to the J6 experimental composition. High-hardness steels are more susceptible to hydrogen cracking, and care is needed to control final hydrogen content. The AREA rail specification does not specify hydrogen content, but the draft new European specification sets a maximum of 2.5 parts per million for premium rail steel. Exhibit 1 shows that the steel-making process has given a hydrogen level well within this limit.

The microstructure and cleanness of the test rail was characterized at OGI using electron and optical microscopy. The microstructure consisted of lath bainite with no visible carbides, similar to the experimental J6 steel. There was no evidence of sulfur segregation. The rail samples included dispersed angular inclusions (probably nitrides), with an estimated volume fraction of 0.16 percent, formed as a consequence of the need to protect the

Alloying	Steel		
Element	J6*	J6 rail	HH**
C	0.26	0.26	0.79
Mn	2.00	2.00	0.91
Si	1.81	1.84	0.66
Cr	1.93	1.94	0.47
Mo	0.49	0.44	n/a
B	0.003	0.0026	n/a
P	0.009	0.008	0.018
S	0.010	0.006	0.010
H	n/a	1.1***	---

* Original experimental alloy
** Typical head-hardened rail
(All values weight percent, except: *** = parts per million)

Exhibit 1. Alloy Content of Bainitic Test Steels and Head-Hardened Rail (Values in Weight Percent)

boron from nitrogen. The nitrides are small (typical length less than 3 ten-thousandths of an inch), and should not affect the trials, but their avoidance should be considered for volume rail production as they may adversely affect long-term fatigue performance.

MECHANICAL PROPERTIES

The test rail had a near uniform hardness through its section, with typical Brinell hardness of 430 (head), 415 (web), and 420 (foot). This compares with 422 Brinell found in the experimental J6 steel, and premium rail which has typical head hardness of 340 to 390 Brinell. Steel hardness appears important for rails as studies have shown that high hardness increases wear resistance.[2]

Measured tensile and impact properties of the test rail are compared with typical values for head-hardened steel in Exhibit 2. The tensile properties of the test rail were measured on specimens taken longitudinally from the head, web, and base of the rail. Eight specimens were tested. Tensile strength was consistent throughout the bainitic rail at an average of 208.6 ksi. The yield strength was highest in the base, and lowest in the web, but gave an average of 144.1 ksi. The bainitic tensile and yield strengths are both higher than those typically found in premium rail. Likewise, the bainitic impact energy at room temperature was higher than premium rail. There is concern with the bainitic rail ductility values, which show wide scatter. The maximum values are high, and indicate a material with inherently good ductility. However, the steel is hard, and likely to be notch sensitive. The low ductility values may reflect the effect of specimen preparation or very small surface breaking inclusions. This needs more investigation.

Property	Steel	
	HH*	J6 rail
Tensile strength (ksi)	175	208.6 (203.1 – 216.0)
0.2% Proof stress (ksi)	125	144.1 (129.5 – 154.1)
Elongation (%)	11	8.8 (4.0 – 15.0)
Reduction of area (%)	–	18.8 (2.8 – 43.8)
CVN (-25° F)	–	7.5
CVN (65° F)	4	8.0
CVN (125° F)	–	13.0

* Typical head-hardened rail

CVN - Charpy V-notch impact energy (ft lb)

Exhibit 2. Mechanical Properties of Bainitic Rail Steel and Head-Hardened Rail

RESIDUAL STRESS MEASUREMENTS

The bainitic rails were roller-straightened, and there was concern that their higher strength would lead to higher tensile residual stresses, and a consequent increased risk of sudden rail failure from accelerated fatigue.

Residual stress in the bainitic rail was determined by two methods: web saw cutting and strain gage saw cutting. At a rail end, the web of roller-straightened rail generally has a high vertical residual tensile stress. The AREA web saw-cut test consists of cutting longitudinally through the web of the rail at the neutral axis and measuring the change in rail height. The relaxation of residual stress gives a change in rail height which must not exceed 0.148 inch for a 24-inch rail, cut a length of 16 inches (two-thirds of total rail length). Due to equipment limitations, an 18-inch J6 rail was cut a length of 15 inches. At a cut depth of 12 inches (the same two-thirds of total rail length), the web opening extrapolated to a 16-inch cut was 0.088 inch. At the cut depth of 15 inches the extrapolated opening was 0.075 inch. Thus, the extrapolated web saw-cut opening was well within the current accepted limit.

Longitudinal residual stress was also measured by fixing strain gages to the head, web, and base of the test rail, and relieving strain by cutting around the gages. The strain relaxation measured by each gage gives the value of residual stress at that point. Measurements were made on two bainitic rail samples, each 3 feet long. Values obtained are shown in Exhibit 3, and compared with typical values from 340 Brinell and 370 Brinell premium rail. There are two points to note. First, the damaging tensile residual stresses in the head and base of the bainitic rail are no worse than those in premium rail. Second, the stress pattern in the web of the bainitic rail appears different from that in premium rail. The pattern was repeatable, and is believed to be authentic because the test method has been used on other rails with consistent results. Its cause is unknown, but it is not likely to affect performance.

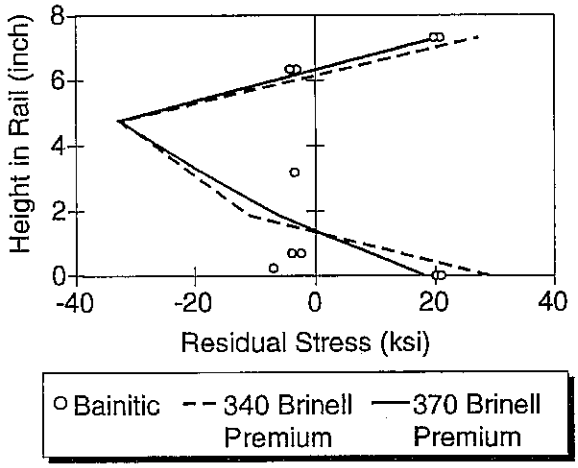

Exhibit 3. Residual Stress of Bainitic Rails and Two Premium Rails

WEAR PROPERTIES

Laboratory wear tests were made on test-rail specimens to compare with wear results for premium steel and experimental J6 steel. Tests were done in an Amsler machine, using cylindrical specimens from the railhead and mating wheel steel specimens, at contact stresses of 177 ksi and 247 ksi, and creepage of 35 percent. These conditions simulate severe dry wear at the gage face of high rails in sharp curves[3]. In earlier tests under these conditions, premium rail showed severe wear, while the experimental J6 steel showed much lower mild wear. Because different types of wear were generated, the results suggested only that the J6 steel was probably more wear resistant than premium rail steel. In the latest tests, the J6 test rail showed severe wear, just like the premium rail, but it gave a wear rate about one-half that of premium rail (see Exhibit 4). This is encouraging, and gives hope that the J6 rails will show good wear resistance in full track tests.

Steel	Wear Rate (mg/m/mm)	
	177 ksi	**247 ksi**
J6*	78***	136***
J6 Rail	2,420	4,240
HH**	5,966	8,149

* Original experimental alloy
** Head-hardened premium rail (~ 350 Brinell)
*** No Type III wear generated

Exhibit 4. Wear Rate of J6 Bainitic Rail and Laboratory J6 Steel Compared to Head-Hardened Pearlitic Rail

FUTURE WORK

Three 80-foot lengths of J6 test rail will shortly be installed in Section 7 at FAST, a dry 5-degree curve which also holds currently available and new premium rail steels. Profile measurements made at intervals on all rails will characterize and compare wear performance. If the bainitic rails show better wear performance than premium rail, further work will be undertaken to obtain optimal service performance.

REFERENCES

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2 J.S. Hannafious, "Results of Rail Wear Tests at FAST," 1st Annual Research Review, Vol. 1: FAST/HAL Test Summaries, Association of American Railroads, Pueblo, CO, 1995, pp. 35-41.
3 P. Clayton, "Predicting the Wear of Rails on Curves from Laboratory Data," Wear, Vols. 181-183, 1995, pp. 11-19.

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