TECHNOLOGY DIGEST
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"PRELIMINARY SPALLING STUDY AT THE TRANSPORTATION TEST CENTER,"

by Britto R. Rajkumar and Daniel H. Stone

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Summary

The causes of wheel spalling, which result in the expulsion of metal from the wheel tread and, if too severe, in wheel removal, are not well understood. A study was recently carried out to evaluate factors involved in the wheel spalling of 100-ton capacity coal cars. Testing was conducted at the Transportation Test Center (TTC), Pueblo, Colorado, with primary funding from Johnstown America Corporation and additional participation by Southern Company Services and St. Johns River Power Park. Since the results of this program are of interest industry-wide, the AAR also participated as part of the Vehicle Track System Research Program at the Chicago Technical Center.

The study was based on the hypothesis that spalling defects are produced by wheel sliding under various operating conditions. The AAR was able to produce wheel sliding on both aluminum and steel cars under a combination of braking and adhesion conditions. For a given brake application, the single most important condition that led to wheel sliding and subsequent spalling was a low level of coefficient of adhesion with track contamination. The other conditions that led to wheel sliding were, in order of importance: a non-operative empty/load device; the bounce of wheel on rail, resulting in the reduction of vertical wheel load; and extreme sharp curvature.

Wheel sliding produces high enough temperatures on the tread to metallurgically transform a thin surface layer of pearlitic structure to untempered martensite. The latter has a crystal structure approximately 4 percent smaller than the base pearlitic structure and is extremely brittle. This results in high residual stresses surrounding 0.02 inch to 0.20 inch thick patch martensite and subsequent expulsion of the metal from the tread during revenue service.

The tests examined various combinations of dynamic conditions, operational braking practices, empty load device configurations of aluminum cars, and adhesion levels in the wheel/rail interface leading to wheel slide.

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INTRODUCTION AND CONCLUSIONS

Johnstown America Corporation contracted with the AAR to investigate wheel spalling failures occurring on aluminum and steel cars operated by the Union Pacific Railroad (UPRR). The Southern Company Services participated in the investigation by adding an aluminum car to the test consist. St. John's River Power Park also participated in the program by adding the third aluminum test car. Both the UPRR and St. John's River Power Park have experienced significant amounts of wheel set removals from service on account of wheel spalling. The main emphasis of the study was to validate the hypothesis that wheel sliding, due to empty car dynamics, was the dominant phenomenon which led to spalling. The tests conducted at TTC, with three aluminum and one steel car, investigated the various conditions that resulted in wheel sliding.

The loss of relatively large pieces of tread material has been defined as shelling or spalling. Shelling is defined as loss of tread material from the action of rolling contact fatigue. In wheel spalling, the formation of thin layer of martensite on the wheel tread has at least two possible origins. The first of these is the development of local hot spots in excess of 1333°F, which is the minimum temperature for the formation of martensite during subsequent cooling. The second origin is through rapid frictional heating during wheel slip or sliding. During this program, the AAR was able to demonstrate the second origin of martensite formation through wheel sliding as the primary cause of wheel spalling defects.

The following conclusions were drawn from the results of on-track tests carried out at TTC:

- The tread defects produced at TTC due to gross wheel slide and chain slide (evidence of intermittent sliding around the tread circumference) were similar to those spalling defects observed in unit coal train service.
- The formation of martensite around the spall defects, produced at TTC, was confirmed by etching the tread surface.
- The most dominant parameter which contributed to wheel slide for a given brake cylinder pressure (BCP) was a very low level of coefficient of adhesion with track contamination.
- The disabled configuration of the empty/load device on the aluminum cars seemed to be the next important parameter which resulted in wheel slides at relatively higher BCP's.
- Severe tread defects were produced with gross wheel slides that extended up to 75 seconds at 30 mph to 40 mph.
- Of all the perturbed test zones, the pitch and bounce section produced most of the wheel slides observed at TTC
- The steel car without empty load devices had a higher propensity of wheel sliding at relatively higher brake cylinder pressures compared to aluminum cars with operational empty/load devices

The following recommendations are being proposed by the AAR to investigate the growth of wheel spalling in regular service and validate the findings of on-track tests carried out at TTC:

- Selected wheel sets with tread defects produced under this program have been subjected to metallurgical anaylsis to verify the accuracy of transformation models.
- Since wheel set vertical dynamics was shown to play an important role in the initiation of wheel slides (for a given brake application under low levels of adhesion), more testing may be required to qualify this mechanism.
- Testing in an actual railroad service environment with additional instrumentation to characterize the behavior of brake rigging, including monitoring of brake shoe normal force, tangential force and wheel tread temperature is underway.

FULL SCALE TESTING AT TTC

The test train primarily consisted of four hopper cars (one steel and three aluminum). The brake rigging for the test cars was of bottom-rod-under bolster configuration. The three aluminum cars had Ride Control trucks with three different types of empty load devices, whereas the steel car had Buckeye trucks with no empty load device.

Tests were carried out with empty cars under full service braking and dry adhesion conditions on various sections of the test tracks such as different degrees of curvature, turnouts, dynamic curving, spiral negotiation, twist and roll, followed by pitch and bounce. The dominant test zone which produced wheel sliding of the above track sections was the pitch and bounce section of the Precision Test Track (PTT). The Tight Turn Loop (150 ft. radius curve with restraining rail) did show the evidence of wheel lockup under extremely low speed and 20 pounds per square inch reduction. However, no tread damage was observed due to this test on the sharp curve.

The critical measurements in the instrumentation set up for the four test cars pertained to the direct-current speed tachometers, which monitored wheel slip and slide on all wheel sets during the on-track tests. The remaining measurements consisted of instrumented bearing adapters to monitor wheel unloading on the second and fourth axles of the lead aluminum car (especially on the pitch and bounce section), BCP and secondary spring nest deflections (on all the test cars), and train speed. Any wheel slip encountered during the on-track tests was detected by measuring the difference between the train speed and the corresponding wheel set speed. If any wheel slip activity was detected during the tests, the wheels of interest were inspected and the wheel defects, such as flats and chain slide, were documented.

Over 100 test runs were carried out under this program which included the following varied conditions.

- Different levels of brake cylinder pressure on all the test cars with and without empty/load device operative for aluminum cars
- Dry conditions on rail and in the test zone
- Water sprayed on rail to simulate rainy conditions
- One percent soap solution sprayed on rail to reduce the coefficient of adhesion on rail, simulating contaminated conditions

Out of the above tests carried out on various test zones at TTC, significant events such as instantaneous wheel slide, partial slide and chain slide occurred in 15 tests. Exhibit 1 presents the summary of test conditions and parameters which resulted in significant events. The majority of events occurred on the pitch and bounce section of the PTT, as expected. Most of the tests were conducted at 40 mph, which is the normal operational speed of unit train service. The data collected during the above test runs was analyzed and the time history plots of train speed, individual axle speeds, brake cylinder pressure, computed braking ratio (from the static tests conducted earlier), bearing adaptor loads, and secondary spring nest deflection were produced.

Exhibit 1. Summary of Test Conditions and Parameters which Resulted in Wheel Sliding

RUN No.	LUBE	RAIL ADH.	BRAKE CYLINDER PRESSURE (psi) * = Disabled Empty/Load Device + = Wheel Slide Occurrence			
			CRL (aluminum)	WFAX (steel)	DEGX (aluminum)	SJRX (aluminum)
208	DRY	.35/.38	42	67+	42	46
209	DRY	.35/.38	*+64	66	40	47
226	WATER SPRAY	.26/.28	*+65	67	*+67	*71
242	DRY	.41/.52	*+64	64	*66	*68
243	DRY	.55/.55	*+64	63	*66	*68
244	DRY	.41/.52	*+66	+71	*73	*+75
246	SOAPY	.24/.15	*+43	44	*46	*49
247	SOAPY	.24/.15	*+41	45	*+50	*49
248	SOAPY	.24/.15	*+31	32	*33	*35
254	SOAPY	.24/.15	+39	+67	41	48
258	SOAPY	.24/.15	35	+64	35	41
259	SOAPY	.24/.15	34	+63	35	40
261	SOAPY	.24/.15	33	+59	33	38
263	SOAPY	.24/.15	35	+62	35	40
266	SOAPY	.24/.15	+36	64	36	41

Note: Contact Britto R. Rajkumar at (719) 584-0566 or Daniel H. Stone at (312) 808-5806 with questions or comments about this document.

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