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Key Findings

- Different vertical loading on the high and low rails, associated with unbalanced running conditions, influenced the wear and RCF behavior of the wheels and rails.
- Higher vertical loading increased the severity of surface-initiated RCF whether on the high or low rail.
- Compared with dry running conditions, lubricated running conditions reduced the amount of wear and the severity of RCF on the lubricated wheel and rail.

MxV Rail, a subsidiary of the Association of American Railroads, performed the research described in this publication.

RCFS Testing of Curve Superelevation Effects on RCF Formation

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The superelevation within a curve of given curvature determines the balance speed of that curve. The vehicle speed in the curve determines whether the vehicle runs over, at, or under the balance speed. The vehicle speed and, consequently, the balance condition in the curve effects the forces at the wheel-rail interface.[1,2] Using its Rolling Contact Fatigue Simulator (RCFS), MxV Rail performed tests to study the effects of different balance conditions, under both dry and lubricated contact, on the formation of rolling contact fatigue (RCF). These tests were performed as part of the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) program.

INTRODUCTION AND BACKGROUND

The balance speed within a curve is the speed at which the perceived "centrifugal force" toward the outside of a curve counteracts the gravitational force component directed toward the inside of the curve due to the superelevation of the track. In the following discussion, when the train travels faster than the balance speed, the vehicle is in an overbalance condition or it is curving with cant deficiency. When the train is traveling slower than the balance speed, the vehicle is in an underbalance condition or curving with cant excess. Two main effects influencing the wheel-rail interaction forces stem from the curving speed.

The first effect is the distribution of the vertical forces where curving at the balance speed equalizes the vertical forces on both sides of the vehicle. Curving at any other speed results in an unequal vertical load between the left and right sides of the vehicle with the overbalance condition resulting in an increase in the vertical load on the outer or so-called high rail. RCF can be initiated on the high rail or the low rail in any balance condition, though the severity of RCF may differ.

The second effect is the lateral force present during curving. Previous research[1,2] has shown an increase in cant deficiency, i.e., curving with overbalance speed, reduced the lateral force on the low rail and reduced the lateral force/vertical force (L/V) ratio on the high rail of a curve due to a reduction in the wheelset's angle of attack (AoA). In the presence of lateral steering forces, friction control is a proven method for reducing the curving resistance and gage face or wheel flange wear.[3] Since lubrication would also change the wheel-rail forces, MxV Rail decided to contrast and compare RCF behavior under dry and lubricated conditions.

RCFS TEST PARAMETERS

The RCFS allows the user to control the movement of a track segment mounted on a reciprocating table relative to a constrained wheelset. Typical curving conditions can be emulated by defining the required vertical wheel loads, lateral displacement, AoA, and roll angle of the wheelset relative to the track centerline. The curving condition for both the overbalance and underbalance speeds requires the application of unequal vertical wheel loads.

MxV Rail performed NUCARS®* simulations of a loaded car with AAR-2A wheel profiles running on 136RE rails to determine the typical curving conditions while the vehicle negotiated curves with different curvatures and superelevations. Both overbalance and underbalance speeds that would result in 3 inches of cant deficiency and cant excess were selected and evaluated.

Researchers evaluated the high rail to low rail load ratio results from the NUCARS analyses and decided to use a 60:40 percent ratio to represent an overbalance condition and a 40:60 percent ratio to represent an underbalance condition in subsequent testing. The AoA result showed changes at different balance conditions. For the RCFS tests, the AoA was chosen to be a constant at 4 milliradians (mrad) for the different balance conditions that were tested. Although the lateral displacement and roll angle of the wheelset could be determined from the simulation, it is more expedient to determine these settings from the RCFS setup since wheel back-to-back, track gage, wheel, and rail profiles can vary within given tolerances from one test setup to the next. Before the start of a given test, the lateral displacement of the wheelset was determined at a value that would cause wheel flange root contact without flange contact. Although every attempt was made to produce flange root contact, the profiles of the rails used in Test 4 to 6 did not allow contact at the flange root, when near or in flange contact. The wheelset roll degree of freedom was set to obtain the load ratio dictated by the balance condition.

The wheels and rails used during the tests had material properties typical of Class C wheels[4] and intermediate strength[5] rails used in North American freight service. Wheel and rail hardnesses can vary within given ranges. The wheelset used during Test 1 and 2 were different from the wheelset used during Test 3, which were also different from the wheelset used during Tests 4 to 6. When required, lubrication was applied by means of a commercial solid lubricant stick angled to contact and lubricate the wheel flange root of the wheel contacting the high rail only. The low rail was kept unlubricated for all six tests. Each test was run for 80,000 cycles, except for Test 3 that ran for 70,000 cycles. Table 1 summarizes the test parameters that were fully defined for the six combinations.

Table 1. Parameters for superelevation tests

Test No.	Balance Condition	Load Ratio (High:Low) [%]	Lubrication State	AoA [mrad]	Lateral Displacement [in.]
1	Under	40:60	Dry	4	0.42
2	Balance	50:50	Dry	4	0.45
3	Over	60:40	Dry	4	0.40
4	Under	40:60	Lubricated	4	0.47
5	Balance	50:50	Lubricated	4	0.46
6	Over	60:40	Lubricated	4	0.40

RESULTS

The two main results of interest for these tests compared the wear and RCF deterioration of the wheels and rails.

Wear Analysis

The transverse wheel and rail profiles were measured with a MiniProf profiler after every 10,000 cycles. Figure 1 charts the cumulative area worn off the wheels and rails for the different tests. Figure 2 compares the total area worn off after 70,000 cycles on the high and low sides of the rails and wheels.

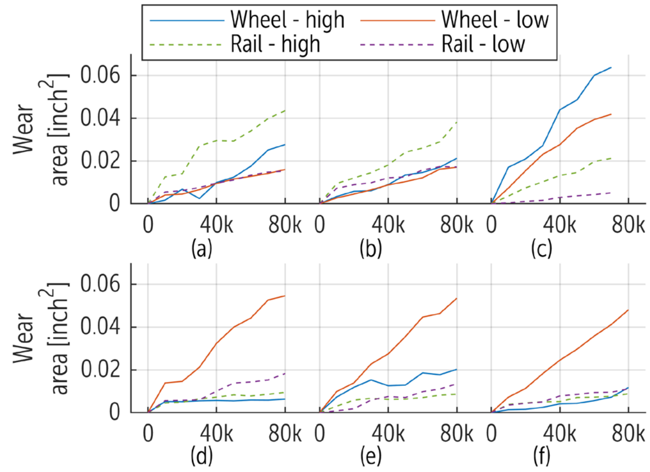

Figure 1. Two-dimensional area worn off for (a) Test 1-Under, (b) Test 2-Balance, (c) Test 3-Over, (d) Test 4-Under, (e) Test 5-Balance, and (f) Test 6–Over

* NUCARS® is a registered trademark of MxV Rail

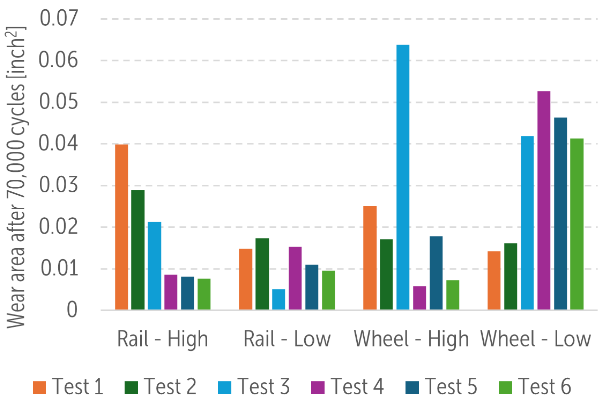

Figure 2. Comparison of the two-dimensional area worn off after 70,000 cycles

Under dry conditions, the area worn off the high rail was greater than the area worn off the low rail while the opposite was true for the lubricated conditions. The lubrication on the wheel flange root on the high rail resulted in less wear of the wheel and rail on the high side of Tests 4 to 6 compared with the wear found during Tests 1 to 3, indicating a reduction in the coefficient of friction at the flange root was beneficial for wear. In Tests 3 to 6, the low rails showed less area loss than the the low rail wheels possibly due to the difference in hardness. The greater worn area of the wheel on the high rail for the overbalance condition (Test 3) was likely caused by the contact position of the wheel and rail. The wheel not only contacted the rail at the flange root, but at the end of 70,000 cycles noticeable flange wear occurred. The additional flange contact that occurred only during Test 3 increased the area worn off the wheel. The wheels contacting the low rails in Tests 1 and 2 had much less wear during the test compared with Tests 3 to 6. The exact cause of this result is not clear though it could be related to variations of the steel properties allowed by the Class C specification[4] between the wheelset of Tests 1 and 2, compared with the rest.

RCF Formation

As discussed by Ekberg et al,[6] the shakedown diagram is often used as an engineering model to assess the likelihood of RCF initiation. According to the shakedown model, RCF initiation is a function of the normal and the tangential forces, i.e., longitudinal and lateral steering forces in the contact plane. The normal force is a function of the vertical load and the contact angle in the contact plane. During the tests, the tangential forces were approximately equal for a given lubrication condition due to similar AoAs and similar lateral displacements applied during the tests. The contact angle during the tests was also similar with the intention of having the flange root of the wheel in contact with the gage corner of the rail. Figure 3 shows the RCF on the gage corner of the high rails for the different tests. The RCF that was initiated during the dry tests (Tests 1 to 3) was more obvious and severe compared to the lubricated tests (Test 3 to 6). The severity of the RCF increased while the vertical load on the high rail increased from Test 1 to Test 3.

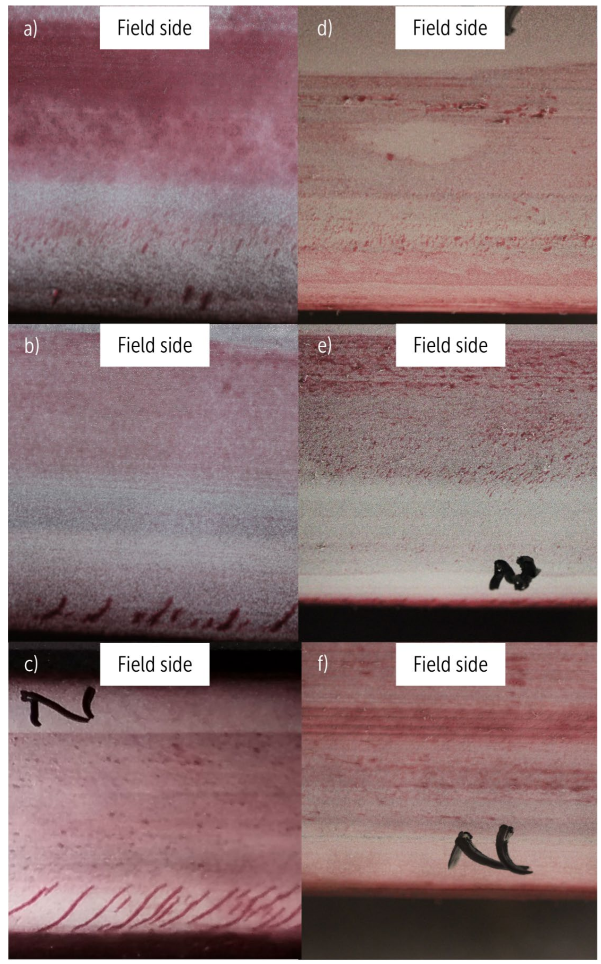

Figure 3. Progression of RCF at 70,000 cycles on the gage corner of the high rail under dry contact conditions for (a) Test 1-Under, (b) Test 2-Balance, (c) Test 3-Over, and lubricated conditions for (d) Test 4-Under, (e) Test 5-Balance, and (f) Test 6-Over

Since the maximum coefficient of friction and, therefore, the maximum achievable tangential forces were limited by the applied lubricant, when the contact conditions changed from dry to lubricated, the tangential forces also changed. The lack of gage corner RCF is evident in Figure 3(d) to (f) for Tests 4 to 6. There were visual indications of RCF initiating toward the crown of the rail profiles where dry contact conditions were present on these rails. The solid stick lubricant had a positive effect on reducing surface-initiated RCF at the rail gage corner.

The RCF progression on the low rail showed the same RCF behavior where higher vertical load resulted in more obvious RCF initiation and growth while lower vertical loads had less obvious RCF initiation (see Figure 4). When comparing the surface conditions of the low rails under dry and lubricated contact conditions, it was determined that the RCF progressions for the low rails were similar. Figure 4 shows the RCF progression on the low rail of the lubricated conditions.

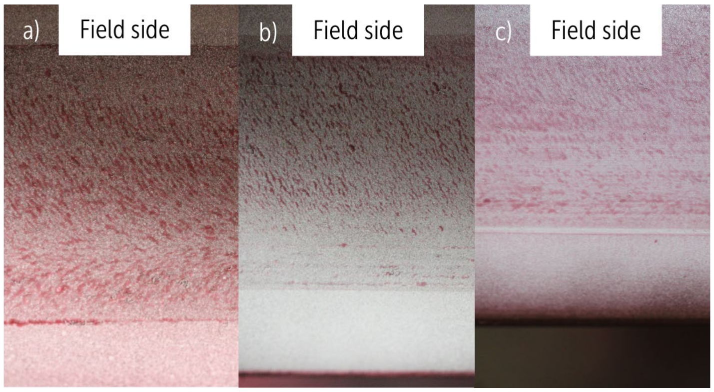

Figure 4. Progression of RCF on the low rail for (a) Test 4-Under, (b) Test 5-Balance, and (c) Test 6-Over at 70,000 cycles

CONCLUSIONS

Tests were performed on the RCFS to determine the effect of different vertical load imbalance conditions within a curve and with dry and lubricated contact. The unbalance conditions resulted in different vertical loading on the high and low rails, which changed the wear and RCF behavior observed on the wheels and rails. Higher vertical loading increased the severity of surface-initiated RCF. Lubrication reduced the amount of wear and the severity of RCF on the lubricated wheel and rail compared with the amount of wear and the severity of RCF under dry running conditions.

The testing on the RCFS may indicate that differences in initial profile and hardness could have a significant effect when trying to compare RCF and wear between different tests on the RCFS. This effect became evident when evaluating the wear results of the wheel contacting the low rail. Additionally, the initial rail profile influenced whether flange root contact could be made and RCF generated at the gage corner. These variables may need to be controlled or accounted for during future testing to facilitate comparison between tests.

ACKNOWLEDGEMENTS

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References

1. Tournay, H., S. Cakdi, S. Trevithick, et al. 2014. "The Effect of Track Cant on Vehicle Curving: Theory & Single Car Test Results Part I of III." *Technology Digest* TD-14-013. AAR/Transportation Technology Center, Inc. (TTCI). Pueblo, CO.
2. Akhtar, M., S. Cakdi, and K. Morrison. 2014. "The Effect of Track Cant on Vehicle Curving: In-service Site Selection & Analysis Part II of III." *Technology Digest* TD-14-014. AAR/TTCI. Pueblo, CO.
3. Lewis, R., U. Olofsson (eds). 2009. *Wheel-rail interface handbook*. First edition. Boca Raton, FL: CRC Press LLC.
4. Association of American Railroads (AAR). 2020. *Manual of Standards and Recommended Practices (MSRP)*. Section G, Wheels and Axles. Specification M-107/M-208: Wheels, Carbon Steel. Washington, D.C.
5. American Railway Engineering and Maintenance-of-Way Association. *Manual for Railway Engineering*: Chapter 4. AREMA. Lanham, MD.
6. Ekberg, A., E. Kabo, and H. Andersson. 2002. An engineering model for prediction of rolling contact fatigue of railway wheels. *Fatigue & Fract of Eng Mater & Struct*; 25: 899–910.

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