On the Suitability of ADI as an Alternative Material for (Railcar) Wheels

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1. Introduction

ADI (Austempered Ductile Iron) offers qualities, which promise to meet the demands of the railroad industry for quieter, lighter, components, while reducing life-cycle costs. In fact, rail to wheel contacts with high normal loads and a contact area of approximately 1cm^2 (as tested here) represent one of the highest loaded roll and slide contact (conditions encountered) in steel. The "self-lubricating" capability of ADI seems to make it an interesting alternative to commonly used steels with respect to maintenance. When compared to steel, ADI exhibits three times higher damping and (thus) promises a decrease in travelling noise. A further advantage is that ADI has a 10% lower density (compared to steel), which allows for lower weight components. The reason for this lower density is the presence of graphite nodules in the matrix structure. These graphite nodules also positively influence the wear characteristics, by acting as a lubricant between the contacting parts.

The Finnish National Rail System (VR) already has experience with the application of ADI for railway wheels (2). In company experiments, they have used ADI (with a minimum tensile strength of 980N/mm^2 and 5% elongation) since 1976 for switching locks and, since 1981, for passenger train car wheels. These wheel experiments demonstrated an estimated 30% reduction in life-cycle cost (from purchase to scrapping). Until now however, no breakthrough in ADI wheels has come for VR, due to wheel tread failures, which in the opinion of the VR were the result of faulty manufacturing, (not the wheel material itself).

In light of this, the Research and Technology center of the Deutsche Bahn AG (DB AG) is presently conducting testing regarding the feasibility of ADI for rail systems. The focus of these tests is to examine the suitability of ADI as a vibration damping material with higher wear resistance for disk brake equipped wheels with speeds of up to 160 kmph. In a research project entitled "ADI-Wheel", (in which train experts, a foundry, and a wheel manufacturer are included), questions dealing with manufacturing methods, component testing, and the estimation of the real to expected damping of traveling noise by using acoustic simulations will be addressed.

One criterion in the selection of wheel materials is their rolling and sliding behavior. To estimate these behaviors ADI was examined in rolling contact with a DB AG rail steel on a roll wear-testing stand. The results of these tests are published here.

2. Experimental Procedure

2.1 Rolling-wear Test

The examinations were carried out using annular tests on a roll wear-testing stand according to the Amsler principle, carried out with horizontally arranged wear rollers (Figure 1). The rate of revolution of the ADI sample (wheel material) was 450 RPM compared to 436 RPM for the rail steel sample. This results in 3% slippage. Strictly speaking, it is not technically correct to refer to this as roll wear testing, since the materials experience a rolling and sliding load during the test.

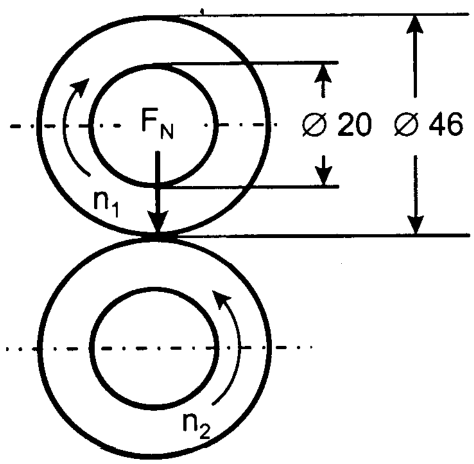

Figure 1: Basic principles of the wear test.

In the tests the normal force (F_n) was varied. It amounted to 1410 N, 3935 N, and 5665 N. In consideration of the varying Young's Moduli (E) of ADI and steel, one is able to calculate the contact force (p_o) as follows:

$$P_0 = 0.418\ \left((F_N \times E) / (r \times l) \right)^{1/2} \qquad (1)$$

with $$E = 2\ (E_1 \times E_2 / E_1 + E_2) \qquad (2)$$

and $$1/r = 1/r_1 + 1/r_2 \qquad (3)$$

where p_0 ... contact pressure in N/mm^2

F_N ... Normal force in N

r_1, r_2... roll specimen radius in mm

l… roll specimen width in mm

The Young's Modulus of ADI was assumed (4) to be E_{ADI}= 160,000 N/mm^2.

Due to the lower Young's Modulus of ADI, smaller contact forces result in the ADI/steel pairing of 700-1400 N/mm^2 and therefore smaller loads in rolling contact than for the steel/steel pairing with surface contact forces of 750-1500 N/mm^2. In an analysis of the tests, the mass loss after 140,000 revolutions of every sample was ascertained, corresponding to a distance of approximately 20km for the ADI rollers. In addition, the rollers were removed and weighed after every 20,000 revolutions, to be able to indicate the incremental and total mass loss at the end of the trial.

2.2 The material

The ADI wear samples were made from a readily available, test ductile iron track plate, which was manufactured using the green sand casting process. A Cu, Ni and Mo alloyed ductile iron, whose Mn content was limited to 0.3% was chosen for the first test wheels. The track plates were austenitized in an inert gas atmosphere at 910°C, quenched briefly in a salt bath operating at 220°C, then immediately transferred to a second salt bath for isothermal transformation (austempering) at 370°C. The test samples were then machined from the austempered plate(s). To test the homogeneity of the properties, 0.2% Proportional (Offset) Yield Strength ($R_{p0.2}$), Tensile Strength (R_m), Elongation (A_5), and notched impact energy (work) (A_v) samples were taken from areas of the track plate with minimum section thicknesses of 20 mm and 60mm. The results are summarized in Table 1. Fractographic examination using a scanning electron microscope confirmed that the one sample with a low impact energy (work) value of 3.5 J, exhibited mircro-porosity.

Section Thickness mm	**$R_{p0.2}$ N/mm^2**	**R_m N/mm^2**	**A_5 %**	**A_V (ISO-V) J**
20	810	1012	6.2	9.3, 9.4, 10.7
60	749	1041	9.5	3.5, 9.3, 10.4

Table 1: Mechanical Properties of ADI samples machined from 20mm and 60mm sections of the track plate material.

The rail material tested was a 900A steel with a pearlitic microstructure and a carbon content between 0.6-0.8% commonly used in the rail network of the DB AG. This steel covers a yield strength range of 880<= R_m <= 1030 N/mm^2 with an elongation of 10%. In order to assure the homogeneity of the samples, especially those of ADI, Vickers (HV 30) hardness measurements at 0.5mm intervals from the surface were conducted on both materials. (Each tabulated value represents the average of four measurements). The results of these hardness tests are given in Figure 2. Accordingly, the hardness values in the ADI samples demonstrated greater variability than those of the steel samples. Furthermore, the ADI was almost 100 points HV harder than the 900A rail steel.

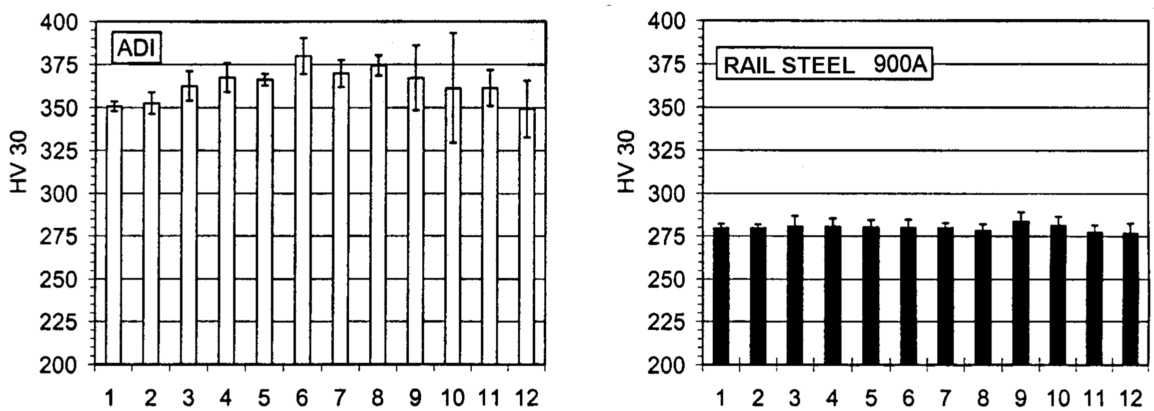

Figure 2- Microhardness traverse data for ADI and 900A Rail Steel

3. Test results and Discussion

In order to examine the wear resistance of ADI as a wheel material, the test results here were compared with those already published by the DB AG for conventional wheel/rail steel pairings, which were tested under the same conditions. These results were gathered (6) and were published (in part) in (7). Figure 3 shows first the cumulative mass lost after 140,000 revolutions for different combinations of material. R7, B6, and HH are all practical application steels for full wheels, wheel rims and rails with carbon contents of 0.5, 0.6, and 0.7% and (respectively):

R_m= 850, 1000, and 1200 N/mm^2

A_5= 20, 14, and 11%.

The values indicated for each combination of material are derived by averaging the four individual readings in each case. As Figure 3 illustrates, the ADI/steel pairing shows the most favorable wear characteristics. Despite the identical hardness of B6 and ADI, the austempered ductile cast iron shows less wheel wear *and* less rail wear for the same test conditions.

At higher contact (normal) forces the favorable influence of the wear systems becomes more apparent, as shown in Fig.4 and Fig.5. Mass loss at higher contact forces can be reduced considerably through the use of ADI, especially in the rail sample. The cause of this is primarily the lubricating action of the graphite. The strain-hardening tendency of the austenitic-ferritic matrix structure must also be emphasized.

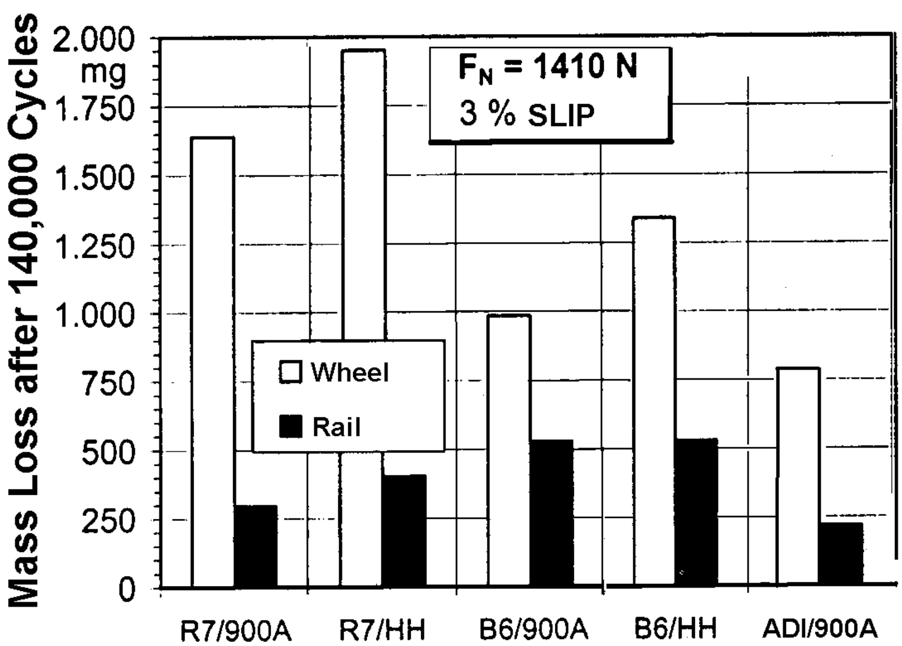

Figure 3- Mass loss for various wheel/rail material combinations at 3% slip and F_N= 1410 N

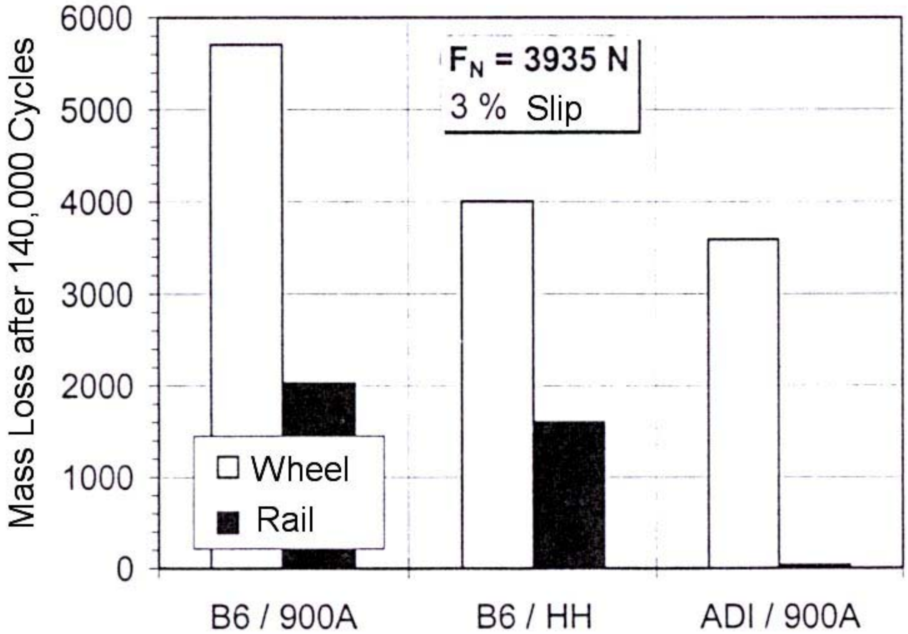

Figure 4- Mass loss for various wheel/rail material combinations at 3% slip and F_N= 3935 N

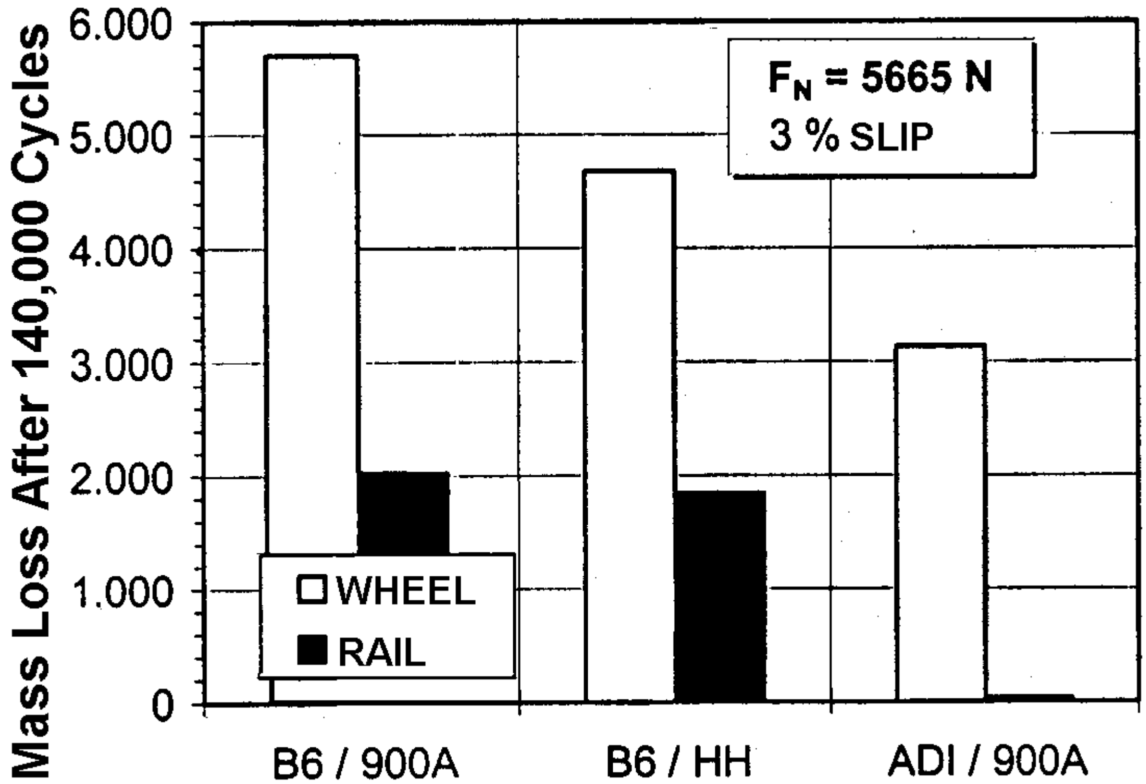

Figure 5- Mass loss for various wheel/rail material combinations at 3% slip and F_N= 5665 N

A more exact interpretation of these results is possible only after consideration of the microstructural processes, on which the following remarks are based. Cast iron with flake graphite, (gray iron), forms a thicker film during sliding friction and therefore demonstrates a better lubricating action than nodular cast iron (8). The superior wear resistance of ADI relative to gray cast iron has been (generally) documented in earlier works (9).

The primary reason for this is the strain hardening (and strengthening) tendency of the carbon-rich austenite, and the high tensile strength of ADI. The formation of an initial wear maximum on the faster running wheel sample, which coincides with the maximum coefficient of friction, is characteristic of all of the tests. This is in agreement with the results of (10).

During the test, the mass loss and the coefficient of friction decrease continually toward a constant (saturation) value. However, with a normal force of 1410 N this saturation value was not achieved with the ADI/900A pairing after 140,000 revolutions. This is explained by the fact that at the lower normal force there is insufficient strain strengthening of the ADI matrix structure on the contact surface. Furthermore, as a result of the lower contact pressure, less graphite is pushed to the surface.

Figures 6 and 7 show the plastically deformed surface regions of the ADI samples, which were stressed under normal forces of 5665 N and 3935 N in the roll wear test. A strain-induced transformation of the austenite to martensite, as observed in other investigations (9), could not be established in this investigation.

However, the graphite nodules are turned in the direction of the loading and show, thereby, evidence of plastic deformation. As earlier investigations have shown, plastic deformation below the contact surface leads to the formation of material “tongues”, which propagate inside the samples as cracks (6). These cracks are recognizable in the ADI samples (Figures 6 and 7), but to a lesser extent than in the comparable steel wheel samples.

Figure 7 shows that these cracks are regularly intercepted by the deformed graphite nodules. Graphite apparently comes through these openings at the sample surface and causes lubrication of the contact area. With increasing pressure, an increase in cracks near the surface was observed in the ADI samples allowing more graphite to reach the contact interface.

In all probability, the fact that wear characteristics are favorably influenced with higher surface pressures is therefore due to a significant strengthening of the surface (or tread) of the ADI sample, *and* by the greater lubrication in the boundary layer between both friction partners, which is missing in the pure steel pairing. In addition, it is observed that the rail steel samples in contact with the ADI show *fewer* cracks, which explains the lower wear on the rail sample (Fig. 4 and Fig. 5). The lower wear on the ADI wheel material is *not* compensated for by a higher wear on the rail material, (as is frequently observed in pure steel pairings) (6).

On the basis of these results, further pursuit of this project seems very promising.

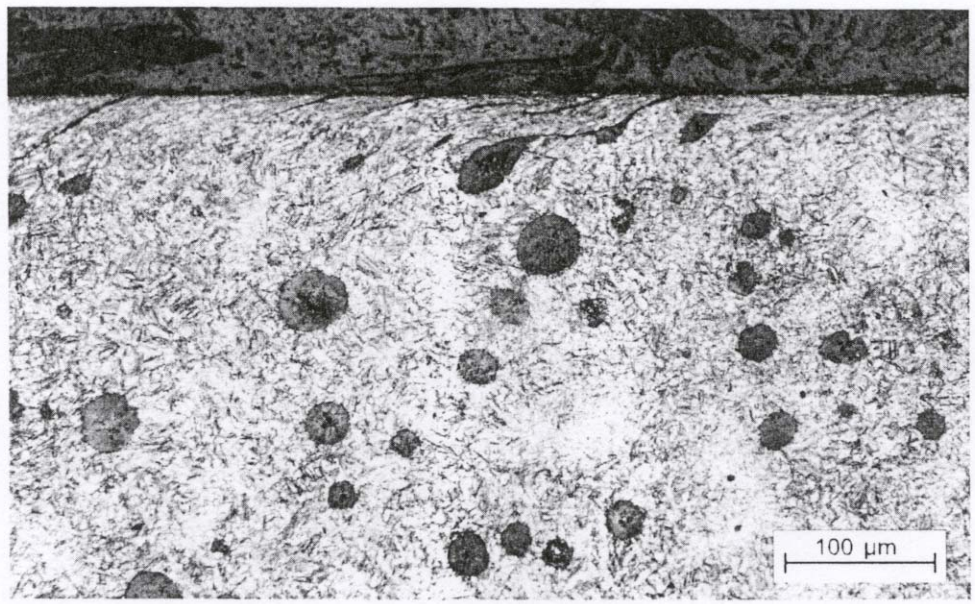

Figure 6- Surface microstructure of the ADI test sample after roll/slip testing at F_N=5665 N

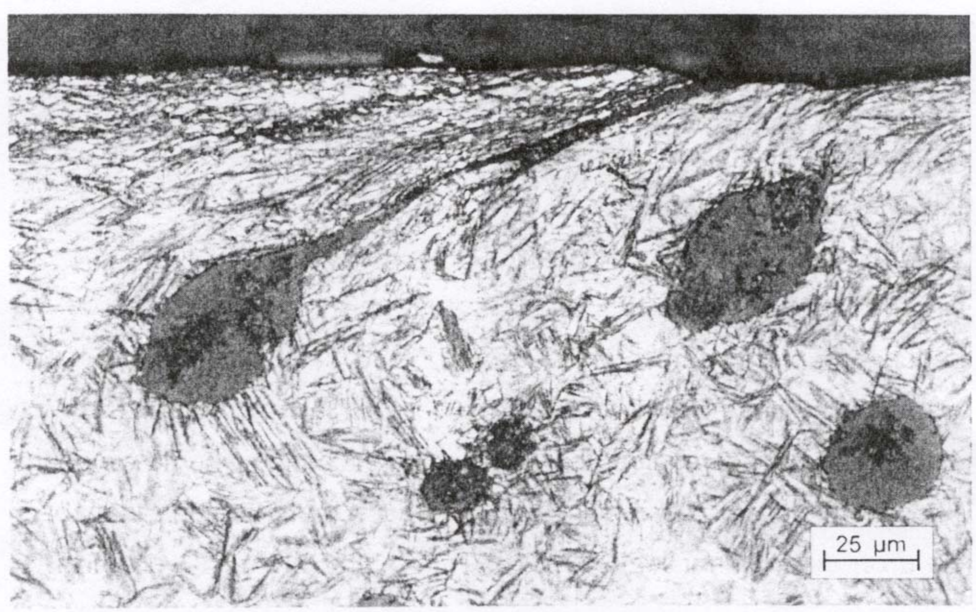

Figure 7- Surface microstructure of the ADI test sample after roll / slip testing at F_N=3935 N

4. Literature

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