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Inspection of friction and wear properties of railway rails

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ABSTRACT

Railway rails work in contact with railway vehicle wheels. During this contact high surface contact stresses and different sliding speeds occur between wheel-rail pair. Stress values that occur on top and side of rail geometry are different. This situation causes wear and damage on rail material in time. In this study primarily the rail material that is used in our country was characterized. Wear experiments are conducted in dry and wet conditions, different contact stresses and sliding speeds in order to sample rail-wheel contact. All wear tests were performed according to DIN 50324 standard with WC ball as counter object in a ball on disc geometry. Wear surfaces were characterized by optically, SEM microstructure analysis and EDS analysis, friction coefficients and wear rates were calculated for every test condition. As a result damage that occurs on rail material during working conditions were tried to be determined.

1. Introduction

Railway vehicles work in contact with railways. Rail wheel contact is an open system. Dirt, humidity and lubricants affect rail-wheel contact. The wear on railways affects not only running speeds and stability but also has an effect on railway safety. In Turkey 1.344.566.000TL was spent on railways[1]. The yearly new railway building capacity is 135km and 6375 km of railway was renovated [2] as of 2011. Planned investments for railway industry necessitate inspection of rail-wheel contact. In order to understand rail-wheel contact characterization of rails is an important step, which also is important in investment planning. Characterization of rail should take into account changing load and wear behavior of rails.

Rail-wheel contact generates different loads on rails. The most obvious reason is different loading on trains; however there are load variations because of curvatures. In studies conducted in Australia, Sweden and Italy contact pressure was found to be between 600MPa – 2700GPa [3–5]. These variations are caused by speed and curvatures. When a train goes into a curvature load on rail gauge increases, this rail-wheel contact pressure distribution was also confirmed by FEA analysis[6].

Material hardness and microstructure influence wear behavior of rails [7]. Pearlitic and Bainitic steels are used for rails. Twin-disc rolling-sliding [8], ball-on-disk [9] were used for laboratory testing of rails. It was found that there is a high correlation between laboratory ball-on-disk tests using a ball with higher hardness with full-scale rail performance tests. Hernandez et al. found that ball-on-disk method is a reliable tool for investigating wear performance [10]. Hernandez et al study also mentions that without incurring any wear on ball at ball-on-disk test allows a direct wear analysis on the rail samples that is similar to full scale FAST tests.

The purpose of this study was to inspect and evaluate friction and wear behaviors of rail tracks used in our country under dry and wet conditions. In order to achieve this, samples taken from used rail track material were simulated under working conditions in laboratory and results were examined.

2. Materials and Method

In this study microstructure and wear tests were performed on used railway track samples. The chemical composition and hardness value of railway track that used in this study was given in Table 1. The railway track material is otectoid non-alloyed steel. Samples were cut from railhead of used railway track. The specimens were mounted and their surfaces were prepared in automatic grinding-polishing machine. Microstructures of samples were observed after samples were etched with a 2% Nital etchant.

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Table 1. Chemical composition of railway track material (w.t.%)

C	Si	Mn	P	S	Hardness (HV)
0.778	0.229	1.018	0.022	0.023	310

The wear tests were performed in a CSM ball-on-Disc tribometer (Figure 1). 8 samples were tested on the tribometer for varying sliding speeds at dry and wet conditions. Schematic representation of samples taken from rail track section and wear track are given at Figure 2. Half of these samples were used in dry testing, half were used in wet testing. Dry condition experiments were performed at 30°C room temperature and in 30-35% relative humidity conditions. Wet condition experiments were performed at 29.3°C water temperature with samples in pure water bath. Water was changed for each experiment and bath was cleaned. As counterpart ball for each of the tests WC (E=690 GPa, Hardness=91.2 HRA) ball of 3mm diameter with certified sphericity and composition by RedHill Precision was used. The ball was chosen as WC so no wear will occur on WC ball. In wear tests an 8N load was applied to samples. Test speeds were 5 cm/s, 7.5 cm/s, 10 cm/s and 12 cm/s. The surface roughness values of the specimen surfaces were measured using Mitutoyo SJ 401 surface roughness instrument (Figure 3).

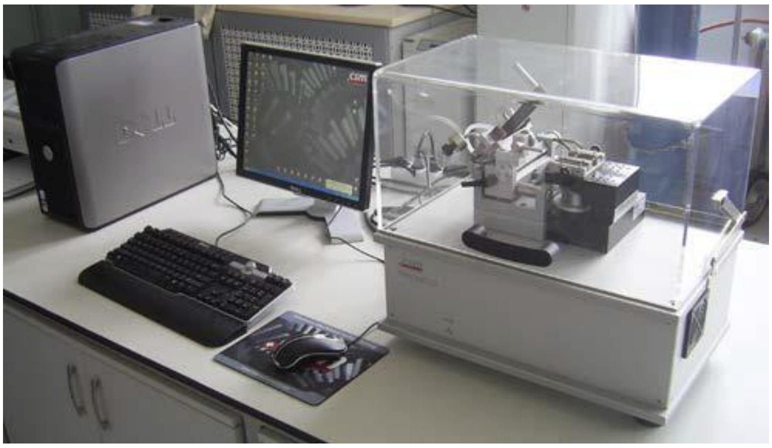


Figure 1. CSM tribometer

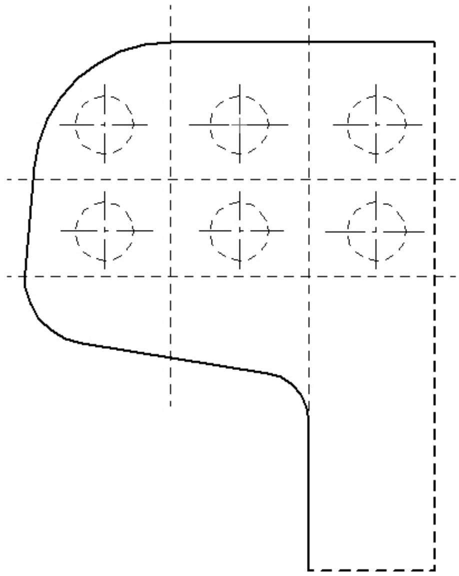


Figure 2. Schematic drawing of railway rail.

Figure 3. Mitutoyo SJ-401 surface profilometer

Wear track images were obtained by Zeiss EVO 50 SEM. EDS analyses were conducted using Bruker axs EDS on SEM.

3. Results and Discussion

3.1.Surface Roughness

Wear test samples were grinded with 500 grid emery paper. Wear test samples weren't polished. Samples that were used in wear tests were prepared to have the same surface properties and surface roughness values before experiment were brought to Ra=0.106μm level.

3.1.1 Wear Behavior

Wear tests were conducted by using a 3mm diameter of WC ball against rail track material in Ball-on-Disk geometry. Applied normal force is 8N. The contact stress this load generates on material was 1.84 GPa. This value is high enough to cause plastic deformation on material. Wear test on material was conducted on these harsh conditions. Wear tests were conducted under normal loading at 5 cm/s, 7.5 cm/s, 10 cm/s and 12 cm/s sliding speeds and varying environments. The load and speed conditions in literature for rails were 1.5 GPa and 10 cm/s [4]. The sliding speed and loads were chosen according to literature. Wear geometry is given at Figure 4.

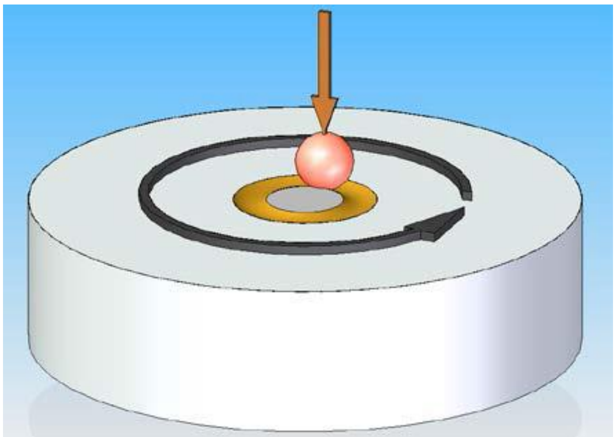


Figure 4. Wear geometry

Wear profiles were measured with profilometer from surfaces after wear tests and specific wear rates were calculated according to these profile areas. Wear rate with respect to sliding speed and friction coefficient are given at Figure 5. Friction coefficients with respect to road values are given at Figure 6.

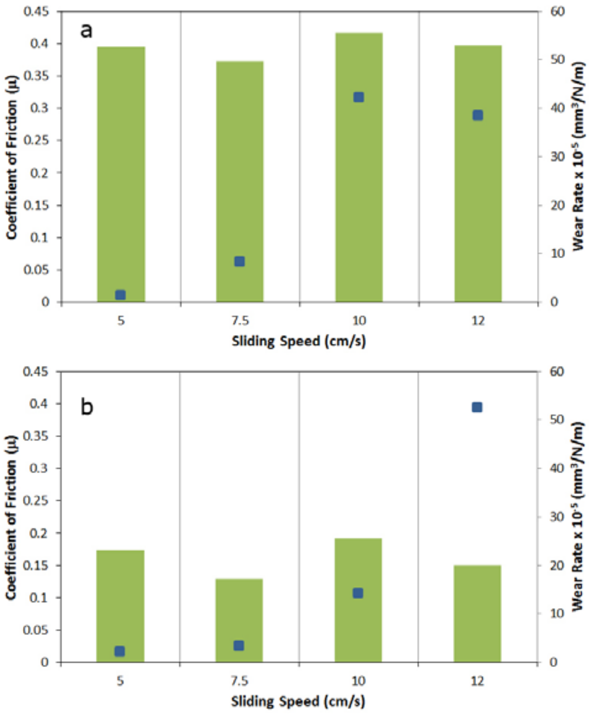


Figure 5. Coefficient of friction and wear rates diagram respect to sliding speeds a. dry, b. wet conditions.

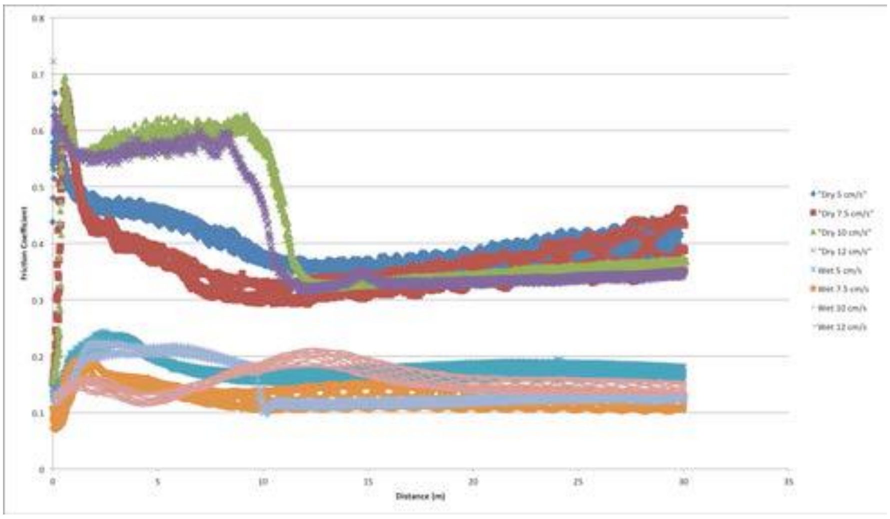


Figure 6. Coefficient of friction vs. distance dry and wet conditions.

It was observed that average friction coefficient of dry condition tests were 0.38, on the other hand average friction coefficient of wet condition tests were at 0.15 level. This situation shows that wet condition friction coefficient is less than half of dry condition friction. When wear rates were observed, it was seen that there is low wear rate at lower sliding speeds and both conditions has the same level of wear rate, however at higher sliding speeds both conditions show an increase in wear rates. Pure water was used in the experiments for wet condition simulation. Fluids with low viscosity can't generate enough film thickness at high speeds and as a result of this wear increases in wet condition thus at high speeds it can be concluded that contact surfaces experience dry conditions.

3.1.2 Microstructural Results

Optical microscopy images of samples were given in Figure 7. The matrix structure of materials was fully pearlite phases.

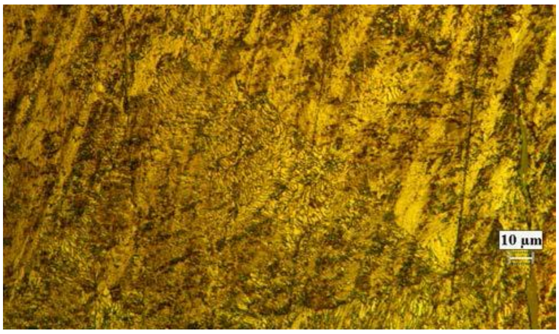


Figure 7. Microstructural image of railway track, 2%Nital, 500x

Worn Surfaces

Wear test samples' SEM images are given at Figure 8 and Figure 9. EDS results of samples tested at 12 cm/s speed at dry and wet conditions are given at Figure 10 and Figure 11 respectively.

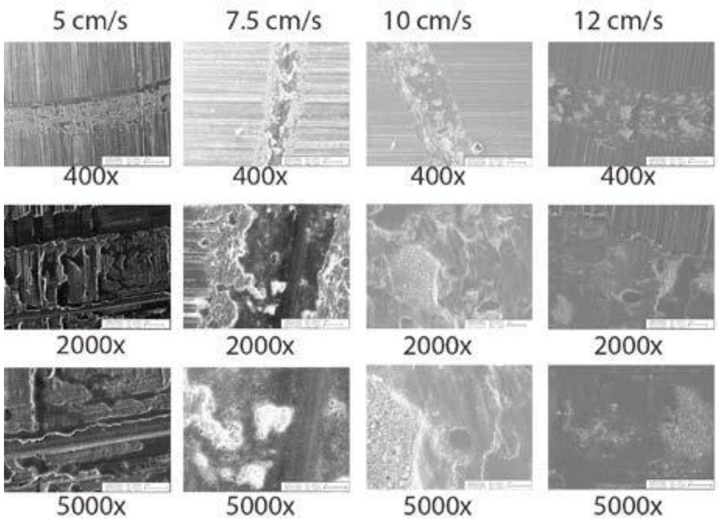


Figure 8. SEM images of samples tested at Dry Conditions

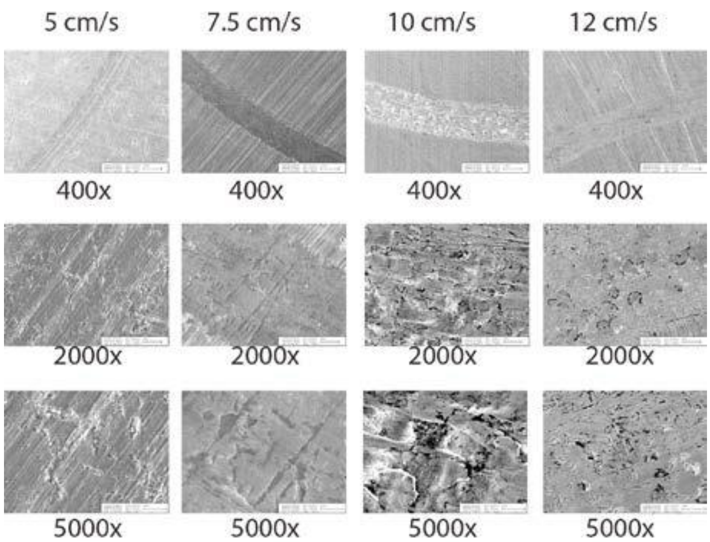
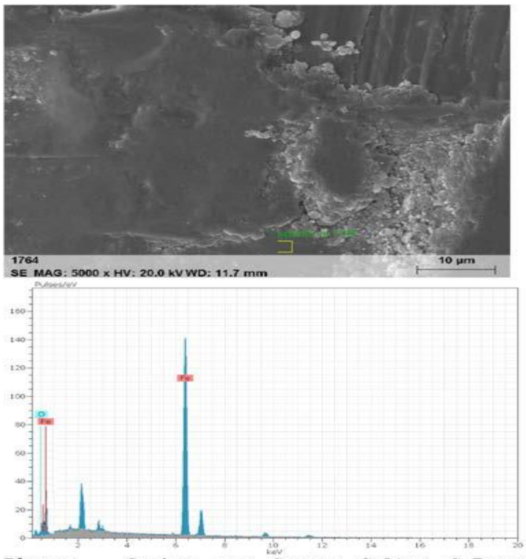


Figure 9. SEM images of samples tested at Wet Conditions

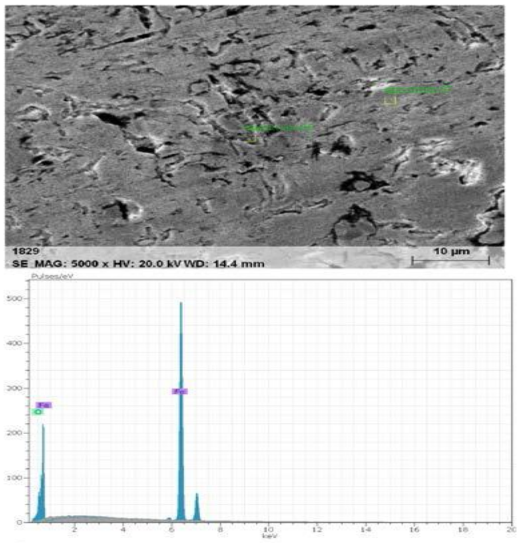


Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Iron	K-series	81.34	53.35	37.97	2.3
Palladium	L-series	2.65	1.74	0.65	0.2
Gold	L-series	33.52	21.98	4.44	1.4
Oxygen	K-series	34.96	22.93	56.95	22.3
	Total:	152.47	100.00	100.00	

Figure 10. EDS result of sample tested at Dry Conditions at 12 cm/s speed

Oxide formations on wear surfaces were observed at both dry and wet conditions. It is possible that oxides formed at wear surfaces to behave as solid lubricants. Fe_2O_3 has wear increase effect on the other hand oxides at Fe_3O_4 form act as solid lubricants [11]. Principally at high speed dry condition wear tests, the Striebeck Curve was observed. Striebeck curve can only be seen when a lubricant is acting on contact surfaces. This result is another finding that supports formation of Fe_3O_4.

Examining EDS results show that there exists a continuous and much denser oxide layer was formed on surfaces. It could be said that much more Fe_3O_4 was formed on surface under this condition. More sparse and small sized oxide formations are observed on surface tested under wet conditions. It is thought that these oxide forms are Fe_2O_3. Particularly it was observed that oxides formed in experiments at 12 cm/s speeds under wet conditions were easier to break thus this generates an abrasive effect and increases wear.



Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	0.97	0.93	3.14	1.2
Iron	K-series	101.66	96.89	94.16	2.7

Figure 11. EDS results of sample tested at wet condition at 12 cm/s

4. Conclusion

It was seen that experiments conducted under wet conditions generate less friction coefficient for every speed value. However, parallel to increase in speed an increase in wear was observed for both conditions. Using wear resistant material on curved tracks where contact stresses are higher and reducing sliding speed will result in a reduction in wear.

It should be noted that sliding speed will increase at curved tracks increasing road bend radius, by improving road geometry, it would be possible to decrease wear to much lower levels.

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