Railway Wheel Wear Analysis

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ABSTRACT

Wear because of wheel-rail fundamentally impacts railroad activities. Wear of the wheel modifies its profile which bargains the vehicle security and builds the crash hazard. Past explores have zeroed in on wear forecast because of wheel-rail association that critical for various viewpoints, for example, running soundness, traveller wellbeing, comfort, life cycle streamlining, and support plan. This research aims to provide an analysis of the comparison wear of the wheel and to analyze and compare the axle against wear rate. The data of wheel wear were measured by using the Calipri device. It is a wheel measurement device that is a highly precise measurement for predictive maintenance. The data obtained were analyzed deeply to see the pattern of wear rate of the wheel. The analysis shows that the wear rate increase in a smaller radius of the track curve due to the curve effect that happens because of friction between the wheels and the track. The lubrication system offers a potentially cost-effective means to reduce the wear rate of the wheels thus enhance rail wheels' life.

KEYWORDS: *Railway maintenance, wheel, wear rate, wheel flange, wheel wear profile*

1.0 INTRODUCTION

The wear in the driver's seat interface is a significant issue in the railroad field. The development of the profile shape because of wear deeply affects the vehicle elements and its running soundness, prompting execution varieties both in arranging bends and in a straight track. Along these lines, the first profiles must be occasionally restored utilizing turning. The right expectation of the wear rate in a specific setting might be significant in the arranging of the wheelset upkeep intercessions. These essential activities which are intermittently vital, are very burdensome both from a monetary perspective and regarding vehicle's accessibility. Henceforth, it is absolutely worthwhile to lessen their recurrence [1]. As a further application, a dependable wear model can likewise be utilized in the advancement of the wheel profile from the wear perspective. The exploration of an ideal state of the wheel for a specific railroad application might be valuable to ensure uniform wear, which suggests practically stable qualities of the contact calculation. Along these lines, not just the wear rate might be decreased prompting a higher interim between two support intercessions, yet the presentation of the wheel-rail contact might be kept almost consistent in the time [2]. The life of railroad wheels is typically restricted by wear. The wheel surface is exposed to high ordinary and extraneous contact pressure. Contact powers change size and direction as the wheel goes over the rail bends, intersections, and nearby surface irritations. This continually changing contact fix moves over the wheel

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track and to a limited degree the rib. The contact is ostensibly rolling yet a modest quantity of nearby sliding happens at the interface. The measure of sliding relies upon the contact fix calculation, typical power, horizontal power, and grating coefficient. The expulsion of material from the surface by wear is an element of the sliding and contact stresses. These amounts rely upon the railroad vehicle elements that are influenced by the difference in wheel profile shape. Both strength and traveller comfort rely upon haggle wear. There are a few points of interest to be picked up by the accessibility of a solid prescient model of wheel wear. It would permit administrators to successfully characterize support plans for wheel re-profiling. However, it would likewise encourage the plan of vehicles and wheelsets that cause decreased wear to both haggle surfaces [3].

The wheel wear expectation is a key-point in the field of railroad research as it highly affects the prudent and security parts of train set plan, activity, and upkeep. This work planned to execute an adaptable and prescient railroad wheel wear device that beginning from a particular vehicle mission gives the wheel profile development as an element of the distance run. Extraordinary consideration is likewise given to concentrate on how the wear advancement is influenced by the grinding conditions between the haggle [4]. Previously, support re-profiling time frames railroad wheels have been planned by fashioners' experience. These days, more dependable and exact instruments in foreseeing wheels wear movement and wheelset lifetime should be utilized to accomplish efficient and security benefits [5].

In different explores, to describe the wear of the wheel material, wear tests were completed utilizing a twin-circle test machine. These were intended to set up instruments, distinguish wear systems of the wheel material, and decide constants vital for the worn record examination to be done in the displaying strategy. The test circles are powerfully stacked together and driven at controlled rotational speed by free electric engines. Shaft encoders screen the rates constantly [6]. A force transducer is collected on one of the drive shafts and a heap cell is mounted underneath the pressure-driven jack. The slip proportion required is accomplished by a change of the rotational rates. All information is gained on a PC which is additionally utilized for burden and speed control. Circles to be utilized during the test were machined to a distance across of 47 mm with a contact track width of 10 mm. Wheel examples were drawn from the wheel edge equal and as close as conceivable to the external surface. Wear tests were done utilizing the wheel circle as the driving plate and the rail circle as the slowing down circle. An ostensible circle rotational speed of 400 rpm was utilized in the tests. A climate chamber encased the plates and air cooling was given to both [7]. Pull was given to eliminate wear flotsam and jetsam to the investigation. Wear estimation was dictated by mass misfortune from the plates, estimated when tests, and at stretches during introductory tests to decide the number of cycles needed to arrive at consistent state wear. Contact stresses and slip were changed to shift the $T\gamma/A$ boundary for the wear list examination.

In another examination, test work is carried on a full-scale rail wheel test rig. This gear was created to give brisk and reproducible testability of rail wear and rolling contact fatigue (RCF) [8]. The test apparatus can reproduce uni-directional or bi-directional traffic conditions. In this work, just uni-directional running was mimicked. For uni-directional running the wheel is lifted while the rail carriage is returning toward the finish of a pass, and afterwards tenderly set down on the rail to begin another moving cycle. The speed of the test rig is restricted to 1 m/s, permitting a limit of 33,000 wheel passes in 24 hours. Powers are estimated inside the water driven chambers. Rail and wheel positions are recorded in every one of the three measurements with dislodging sensors. Room temperature and air stickiness are recorded during each test. All deliberate information is put away in an information base for post-preparing and test assessment. The rail wheel test apparatus can replicate sensible wheel-rail interface contact under reproducible lab conditions. A large number of the constraints related to twin-plate test machines are kept away from with this hardware. This exploratory methodology is likewise a logical choice to figure power.

In another examination, the improvement of a numerical model for the expectation of the wear in the driver's seat rail interface speaks to an integral asset [9]. In this work, it will introduce a technique to gauge the development of the haggle profile because of wear dependent on a model that joins multibody and wear demonstrating. All the more explicitly, the overall format of the model comprises of two commonly intuitive parts which are the vehicle model (multibody model and 3D worldwide contact model) and the wear model (nearby contact model and wear assessment and profiles update). Concerning the vehicle model and the multibody model executed in the effect rail climate, it precisely recreates the elements of the vehicle, considering all the critical levels of opportunity. The 3D worldwide contact model created recognizes the wheel-rail contact focuses using an inventive calculation dependent on reasonable semi-insightful methods. At that point, for each contact point, the contact powers were determined. As respects the wear assessment, the model depends on a neighbourhood contact model on a trial relationship for the estimation of the eliminated material. The wear model, beginning from the yields of the vehicle model, figures the aggregate sum of eliminated material because of wear and its dissemination alongside the haggle profiles. The evacuation of the material is done considering the three-dimensional structure of the contact bodies and the distinctive time scales portraying the wear development on the rail.

In different explores that have been completed, trial examinations concerning wheel profile wear were performed utilizing a full-scale roller rig. As the outcome, the control unit of the test rig was interfaced with a multi-body vehicle test system, so the references for the various actuators can be characterized to duplicate on the test rig similar stacking conditions got from the mathematical reproduction. Thusly, testing conditions near-standard assistance activity can be gotten [10]. A test arrangement repeating the working states of an inclining body rail vehicle on a conventional line was characterized. This grouping was rehashed a few times and at customary stretches, the wheelset movement and the wheel-rail contact powers were estimated along with wheel profiles in various outspread areas subsequently permitting to characterize a precise information base portraying the connection between the running states of the wheelset and profiles wear. The roller test rig is made out of two inflexibly coupled wheels with a breadth of 2 m, bearing two UIC-69 profiled rail rings. The two wheels are set into pivot by a DC engine. The wheelset is associated with a cross-over shaft, speaking to the half-bogie, through pivot boxes and essential suspensions made out of helicoidal springs and oil dampers.

As the train arranges a bend of a given sweep, there is a firmly coupled collaboration between superelevation, speed, erosion levels, and powers produced between the vehicle and the track [11]. The subsequent powers are thusly, liable for or characteristic of a few injurious impacts. These incorporate the likelihood of crashes, for example, wheel climb or rail rollover, debasement of the track structure, rail and wheel wear, commotion levels, RCF, and related rail surface conditions, just as folding inception, improvement, and energy utilization. As an overall assertion, going over the equilibrium speed for a given bend doesn't quickly deliver negative impacts and may have positive favourable circumstances in-vehicle controlling, approach, and bending conduct [12]. In any case, going beneath harmony speed like overbalanced activity will, in general, bring about expanded power levels because of a move in vertical burden to low rail, decrease in a certain snapshot of directing, and expanded truck slant. At speeds that are altogether underneath balance-speed, the relating power levels can turn out to be especially disturbing which is especially on the low rail. The safety and stability of passengers also the problem that had been highlighted [13]. An analysis of wheel wear on the train should be done to effectively evaluate maintenance intervals and to optimize wheel profiles concerning wear. Figure 1 shows the wheel orientation on the commuter train. Both right and left wheels no. 1 are mounted on axle no. 1. Axle no. 1 is started from side A (driver cab A) of the commuter train [14]. The wheel is identified by numbers, for example, wheel 1R denotes the right wheel no. 1 of the axle no. 1. The commuter train orientation is fixed, which means the driver cab A is always facing KLIA station and driver cab B is facing KLS station.

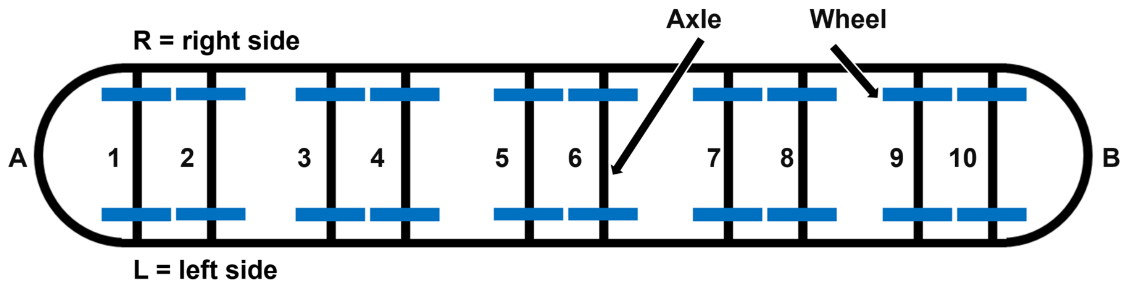

Figure 1: Orientation of the wheel and axle on the train [12-14]

2.0 METHODOLOGY

One of the most important maintenance costs in railway transport comes from the wear of wheel profiles. In the highly competitive railway market, the prediction of wear is then a major concern of the constructors. The actual data collected from the train's company will be analyzed deeply. The data collection shows the reading of flange height and flange thickness. The data were collected by using the Calipri device. Detailed analysis of the rate of wheel wear will be conducted based on the data. The analysis will be started by rearranging the data again and plot the graph. From the plotted graph, the pattern shows the rate of wheel wear in a year. Then, a detailed analysis can be carried out from that pattern and also got the gradient from the graph. Twenty wheels in total are analyzed. Each of them will be analyzed in detail based on the pattern on the graph. Thus, continuous maintenance can be done in a proper way and time.

Calipri wheel estimation is an exceptionally exact profile estimation for prescient upkeep (Figure 2). Calipri non-contact profile estimation gadgets fulfil the needs of the railroad business for prescient upkeep with a reproducible and basic estimation strategy. It attempts to quantify with wheels, brakes, rail, or switches and have the correct answer for any estimation task. For this undertaking, the Calipri C4x arrangement and Calipri Prime were utilized to gauge the wheel [15]. When inspecting flange wear, Calipri Prime ensures user-independent measured values in the micrometer range. Errors in the attachment or reading of the measured values, such as wear gauges or templates for the wheel profile, are a thing of the past. The compact measuring device sits comfortably on the belt and is always available in the pit or on the rails for measuring operations. Depending on the specifications of the plant, employees can either manually copy the measured values into an inspection report or transfer them securely via a USB cable. There are a lot of advantages that eliminate human error for reliable measured values. Firstly, it is a device that is highly accurate measured data. It is also a tamper-proof data transmission. It can be recalibrated independently and have an expandable system.

Figure 2: Calipri wheel measurement device

For wheel profile measurement, the Calipri C4x series is used as a wheel profile measuring tool that eliminates human error. It also a non-contact measurement of wheel profiles same goes for Calipri Prime. The multifunctional Calipri C4x arrangement adjusts to all required innovation and there is an ideal blend from an assortment of estimation modules. The "wheel profile" Calipri module assesses the wear and dimensional precision of railroad vehicles liberated from the human error. The non-contact estimation gadgets likewise depend on laser light segment innovation, consequently guaranteeing exceptionally exact and reproducible estimated information. Very quickly, the main estimated factors show up on the sensor and are naturally contrasted with singular breaking point esteems [10].

The "wheel profile " module is used to measure a complete cross-section of the wheel profile of the railway vehicle in the heavy and light rail sector. In addition to the essential flange measurement which is height, thickness, and cross-dimension, the wheel width, hollow tread, and rollover also can be measured. The sensor is guided physically over the estimation object. As the licensed Calipri strategy naturally makes up for any pivots and inclines, it isn't important to precisely keep up the distance and point to the wheel profile. To take out human blunder for dependable estimated values, this gadget got a lot of points of interest, for example, client free outcomes, computerized information transmission, multifunctional estimation gadgets, and an expandable framework. Wheel wear is a fundamental problem in the railway field. The change of profile shape deeply affects the dynamic characteristics of railway vehicles such as stability or passenger comfort and in the worst cases, can cause a derailment. The invention and analysis of wheel wear have changed the railway field a lot and the statistic of accidents to occur have reduced due to detailed analysis of wheel wear [2]. In railway operations, wear prediction due to wheel-rail interaction is crucial for different aspects such as running stability, passenger safety and comfort, life cycle optimization, and maintenance scheduling [12]. Excessive wear rates on railway wheels can result in rolling-stock derailments. If wear is detected early the possible derailments can be prevented by prematurely replacing wheelsets, although the inventory cost and maintenance downtime remain a challenge [16-17]. Wheels and rails are certainly the most severely loaded structural components with railways. The rolling contact process in the presence of dry friction realizing on the wheel and rail surfaces represents an extremely complicated physical phenomenon. Figure 3 shows a diagram of the wheel whereby T is the flange thickness and H is the flange height. Both T' and H' shows the difference in the length after the wear depth increase. This tells that the flange thickness becomes smaller in increasing mileage while the flange height becomes higher.

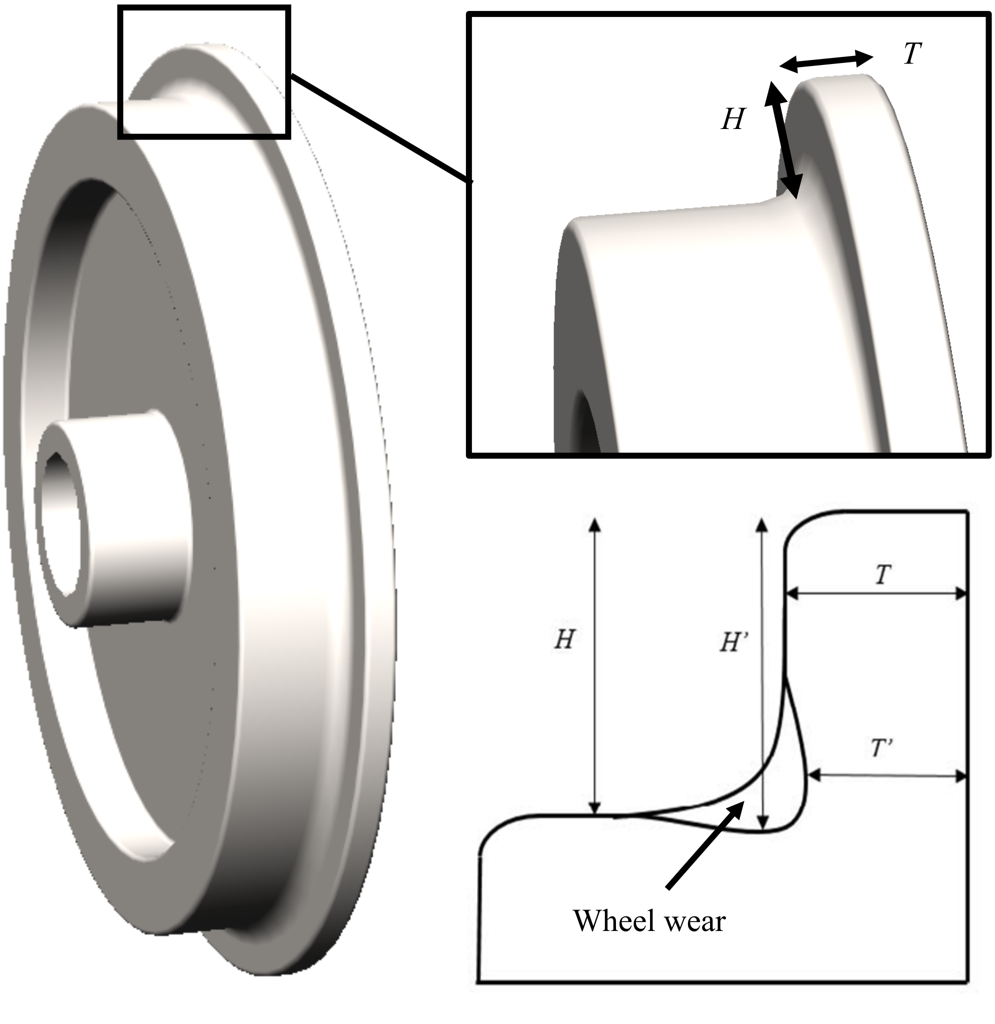

Figure 3: Wheel flange height and flange thickness

3.0 RESULTS AND DISCUSSION

The wear of the railway wheel profile has a very large impact on the operation in railway industries. The regular and irregular wear patterns have an impact on running safety and have a profound impact on train performance. Railway wheels need to be re-profiled at regular intervals, resulting in significant maintenance costs [14]. Manufacturers are increasingly paying attention to the wear phenomenon that occurs through the wheel-rail contact. Due to the friction forces needed to manage the vehicle's braking, acceleration, and guidance, the wheel and rail profiles are subject to some changes, seriously penalizing the vehicle's dynamics, comfort, and safety [15]. Tables 1 to 4 tabulates the wheel profiles of the commuter train.

Table 1: Railway right wheel profile data wheel number 1 to 5

Wheel	**1R**		**2R**		**3R**		**4R**		**5R**	
Mileage (km)	***H***	***T***	***H***	***T***	***H***	***T***	***H***	***T***	***H***	***T***
0	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00
3298	28.50	31.00	28.00	31.00	28.50	31.00	28.50	31.00	28.00	31.00
8889	28.50	29.00	28.50	29.00	28.00	29.00	28.00	29.00	28.50	29.00
19169	29.00	30.00	29.50	30.00	29.00	29.00	30.00	29.00	30.00	30.00
39808	28.50	31.00	28.50	31.00	28.00	31.00	28.50	31.00	28.50	31.00
39808	28.50	31.00	28.50	31.00	28.00	31.00	28.50	31.00	28.50	31.00
53532	29.00	31.00	28.00	31.00	28.00	31.00	29.00	31.00	28.00	30.00
63145	28.00	29.50	28.00	29.50	28.50	29.00	28.00	30.00	28.00	29.50
73008	28.50	29.95	28.50	29.50	28.50	30.00	28.50	30.00	29.00	30.00
80780	28.50	30.00	28.50	29.50	28.00	30.00	28.50	29.50	29.00	30.00
99848	28.35	30.44	28.24	30.49	28.28	30.09	28.20	30.10	28.25	30.09
122200	28.02	29.98	28.24	30.48	28.42	30.43	28.34	30.04	28.41	29.83
130157	28.07	30.02	28.20	30.41	28.35	29.75	29.19	30.07	28.33	29.72
141951	28.27	30.07	28.27	30.32	28.46	29.61	28.31	29.89	28.25	29.39
153601	29.05	30.29	28.36	30.27	28.54	29.49	28.46	29.88	28.46	29.44
160758	28.43	30.03	28.24	30.21	28.56	29.50	28.41	29.74	28.43	29.44
173874	28.72	29.96	28.46	30.14	28.72	30.02	28.59	29.55	28.60	29.35
189042	28.60	29.78	28.51	30.08	28.68	29.09	28.54	29.61	28.60	29.09
201375	28.80	29.76	28.45	29.95	28.65	29.03	28.54	29.50	28.56	29.13
210879	28.59	29.66	28.50	30.03	28.83	28.96	28.59	29.34	28.56	28.79
221765	28.71	29.59	28.48	29.87	28.90	28.76	28.61	29.28	28.76	28.79
231658	29.01	29.69	28.60	29.83	28.95	28.73	28.71	29.31	28.71	28.91
252380	28.87	29.34	28.97	29.27	29.19	28.59	28.78	29.24	28.96	28.73
252411	29.26	29.62	28.65	29.66	29.07	28.53	28.78	29.14	29.00	28.70
261417	28.87	29.28	28.61	29.66	29.14	28.39	28.49	28.79	28.94	28.75
270263	29.14	29.18	28.72	29.60	29.35	28.36	28.86	29.06	29.00	28.40
281548	29.28	29.23	28.79	29.66	29.47	28.41	28.91	28.91	29.06	28.61
290571	29.03	28.90	28.79	29.61	29.60	28.20	28.39	28.30	28.72	28.73
308470	29.40	29.19	28.83	29.48	29.37	27.67	28.65	28.33	28.77	27.78
312106	29.26	29.07	28.92	29.47	29.24	27.61	29.02	28.85	29.34	28.15
322302	29.30	29.05	28.85	29.41	29.33	27.55	28.63	28.28	28.97	27.59

Table 2: Railway right wheel profile data wheel number 6 to 10

Wheel	6R		7R		8R		9R		10R	
Mileage (km)	*H*	*T*	*H*	*T*	*H*	*T*	*H*	*T*	*H*	*T*
0	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00
3298	28.50	31.00	28.50	31.00	28.50	31.00	28.00	31.00	28.50	31.00
8889	28.50	29.00	28.50	29.00	28.50	29.00	28.50	29.00	28.50	29.00
19169	29.00	30.00	29.00	29.00	29.50	29.50	29.00	29.50	30.00	29.50
39808	28.50	31.00	28.00	31.00	28.50	31.00	28.50	31.00	28.00	31.00
39808	28.50	31.00	28.00	31.00	28.50	31.00	28.50	31.00	28.00	31.00
53532	29.00	31.00	29.00	31.00	29.00	31.00	29.00	31.00	29.00	30.50
63145	28.50	30.00	28.00	31.00	28.50	31.00	28.50	30.50	28.00	31.00
73008	28.50	30.00	28.50	29.50	28.50	30.00	28.50	30.00	28.50	30.00
80780	28.50	30.00	28.50	30.00	29.00	29.00	29.00	29.50	28.00	30.00
99848	28.31	30.65	28.15	29.99	28.20	30.37	28.34	30.43	28.23	30.28
122200	28.47	30.49	28.41	30.41	28.37	30.12	28.44	30.44	28.27	29.96
130157	28.32	29.93	28.32	30.29	28.32	30.19	28.39	30.39	28.16	29.86
141951	28.43	29.83	28.38	30.14	28.48	30.06	28.46	30.34	28.43	29.90
153601	28.44	29.72	28.53	30.12	28.46	29.91	28.58	30.19	28.43	29.71
160758	28.49	29.64	28.42	30.08	28.55	29.88	28.54	30.19	28.66	29.93
173874	28.62	29.40	28.62	29.92	28.60	29.73	28.46	30.41	28.54	29.58
189042	28.52	29.33	28.55	29.92	28.66	29.79	28.81	29.88	28.40	29.29
201375	28.59	29.37	28.68	29.89	28.63	29.59	28.85	29.89	28.64	29.38
210879	28.76	29.32	28.76	29.73	28.72	29.64	28.90	29.73	28.87	29.46
221765	28.71	29.26	28.77	29.76	28.41	29.09	29.90	29.74	28.15	28.76
231658	28.79	28.62	28.88	29.74	28.40	29.03	29.04	29.64	28.83	29.19
252380	28.87	29.01	28.86	29.61	28.85	29.36	29.11	29.56	28.92	28.98
252411	28.87	28.94	28.98	29.59	28.52	28.94	29.12	29.53	28.68	28.74
261417	28.75	28.84	28.80	29.51	28.51	28.75	29.13	29.55	28.92	29.04
270263	28.81	28.67	29.01	29.55	28.61	28.72	29.28	29.44	28.47	28.44
281548	29.00	28.78	29.08	29.36	28.58	28.59	29.29	29.34	29.28	28.90
290571	29.00	28.94	29.13	29.40	28.48	28.66	29.36	29.20	28.84	28.52
308470	29.16	28.81	29.29	29.26	29.11	29.04	29.46	29.18	29.02	28.43
312106	29.27	28.71	29.24	29.31	29.13	29.01	29.49	29.08	28.76	28.26
322302	29.05	28.63	29.78	29.30	29.12	29.97	29.48	29.03	29.28	28.62

Table 3: Railway left wheel profile data wheel number 1 to 5

Wheel	1L		2L		3L		4L		5L	
Mileage (km)	*H*	*T*	*H*	*T*	*H*	*T*	*H*	*T*	*H*	*T*
0	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00
3298	28.50	31.00	28.50	31.00	28.50	31.00	28.50	31.00	28.50	31.00
8889	28.50	29.00	28.50	29.00	28.50	29.00	28.00	29.00	28.00	29.00
19169	29.00	29.00	29.00	29.00	29.00	30.00	30.00	30.00	29.00	30.00
39808	28.50	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.50	31.00
39808	28.50	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.50	31.00
53532	28.50	31.00	28.00	31.00	28.00	31.00	28.50	31.00	29.00	31.00
63145	28.00	30.00	28.50	29.00	28.50	29.00	28.00	30.00	28.50	30.00
73008	28.50	30.00	28.00	29.50	28.50	30.50	28.50	29.50	28.50	30.00
80780	28.50	30.00	28.50	31.00	28.00	29.50	29.00	29.00	28.50	30.00

99848	28.29	30.18	28.23	30.67	28.40	30.44	28.33	30.42	28.21	30.11
122200	28.10	29.86	28.26	30.50	28.33	30.36	28.42	30.46	28.36	29.89
130157	28.01	29.80	28.21	30.44	28.35	30.37	28.37	30.29	28.31	29.66
141951	28.46	29.93	28.28	30.42	28.55	30.19	28.40	30.29	28.41	29.56
153601	28.51	29.83	28.39	30.14	28.51	30.01	28.49	30.19	28.47	29.38
160758	28.42	29.77	28.33	30.25	28.59	29.93	28.51	30.26	28.48	29.36
173874	28.60	29.64	28.44	30.25	28.67	29.32	28.56	30.00	28.65	29.28
189042	28.62	29.67	28.49	30.11	28.69	29.86	28.74	30.06	28.64	29.24
201375	28.68	29.52	28.51	30.15	28.76	29.70	28.72	29.92	28.54	29.01
210879	28.73	29.42	28.51	30.04	28.67	29.54	28.69	29.84	28.68	28.79
221765	28.81	29.51	28.52	30.07	28.81	29.97	28.75	29.88	28.79	28.77
231658	28.82	29.36	28.66	30.06	28.84	29.67	28.80	29.79	28.82	28.65
252380	28.99	29.30	28.62	29.85	28.92	29.46	28.97	29.78	29.21	28.44
252411	28.89	29.22	28.76	29.95	28.90	29.54	29.01	29.80	28.81	28.31
261417	28.96	29.21	28.64	29.91	29.00	29.62	28.85	29.71	28.98	28.43
270263	29.07	29.22	28.76	29.78	29.01	29.64	29.02	29.60	29.23	28.39
281548	29.15	29.14	28.84	29.79	29.15	29.49	29.14	29.67	29.29	28.25
290571	29.14	29.11	28.87	29.91	29.12	29.67	29.09	29.58	29.21	28.05
308470	29.14	28.89	28.90	29.64	29.22	29.33	29.16	29.41	29.63	27.91
312106	29.18	29.10	28.90	29.64	29.25	29.51	29.18	29.36	29.72	28.08
322302	29.23	28.68	28.96	29.57	29.15	29.44	29.24	29.41	29.52	27.65

Table 4: Railway left wheel profile data wheel number 6 to 10

Wheel	**6L**		**7L**		**8L**		**9L**		**10L**	
Mileage (km)	***H***	***T***	***H***	***T***	***H***	***T***	***H***	***T***	***H***	***T***
0	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00	28.00	31.00
3298	28.00	31.00	28.00	31.00	28.50	31.00	28.00	31.00	28.50	31.00
8889	28.50	29.00	28.50	29.00	28.00	29.00	28.00	29.00	28.50	29.00
19169	29.00	29.00	30.00	29.00	30.00	29.00	29.00	29.50	29.00	29.50
39808	28.50	31.00	28.50	31.00	28.00	31.00	28.00	31.00	28.00	31.00
39808	28.50	31.00	28.50	31.00	28.00	31.00	28.00	31.00	28.00	31.00
53532	29.00	31.00	29.00	30.50	29.00	31.00	29.00	31.00	28.00	30.50
63145	28.50	30.00	28.50	30.00	28.50	30.50	28.50	30.50	28.00	30.00
73008	28.50	29.50	28.50	29.50	28.50	30.00	28.50	30.50	28.50	30.00
80780	29.00	29.00	29.00	30.00	29.00	29.50	29.00	30.00	29.00	29.50
99848	28.08	30.28	28.20	30.37	28.35	30.11	28.12	30.65	28.26	30.33
122200	28.46	30.45	28.33	30.01	28.35	30.06	28.33	30.50	28.19	29.92
130157	28.42	30.40	28.21	29.97	28.42	29.92	28.18	30.49	28.45	30.25
141951	28.46	30.32	28.38	29.91	28.41	29.96	28.35	30.53	28.61	30.26
153601	28.56	30.24	28.45	29.88	28.56	29.77	28.46	30.49	28.72	30.07
160758	28.58	30.25	28.41	29.80	28.52	29.73	28.38	30.36	28.67	30.16
173874	28.68	30.10	28.48	29.72	28.60	29.71	28.72	29.90	28.75	30.01
189042	28.71	30.02	28.53	29.48	28.57	29.60	28.45	30.31	28.78	29.96
201375	28.79	30.02	28.53	29.56	28.63	29.54	28.53	30.38	28.81	29.90
210879	28.79	29.91	28.61	29.44	28.74	29.28	28.50	30.23	28.78	29.87
221765	28.92	29.97	28.55	29.42	28.76	29.34	28.63	30.31	28.91	29.87
231658	28.96	29.83	28.63	29.37	28.71	29.32	28.72	30.32	29.01	29.80
252380	29.02	29.76	28.77	29.33	28.89	29.30	28.74	30.23	29.15	29.76
252411	29.07	29.69	28.74	29.29	28.91	29.18	28.70	30.17	29.04	29.62

261417	29.04	29.76	28.82	29.31	28.97	29.08	28.76	30.24	29.09	29.72
270263	29.16	29.75	28.85	29.28	28.99	29.33	28.86	30.40	29.20	29.67
281548	29.22	29.64	28.91	29.16	29.05	29.22	28.93	30.37	29.17	29.61
290571	29.33	29.72	28.94	29.10	29.12	28.98	28.95	30.33	28.84	29.52
308470	29.29	29.48	29.01	29.06	29.22	28.82	29.09	30.38	29.02	29.30
312106	29.40	29.57	29.01	29.06	29.17	29.03	28.99	30.35	29.45	29.43
322302	29.39	29.41	28.99	28.95	29.20	28.86	29.02	30.32	29.64	29.47

From the results in Tables 1 to 4, the graphs of flange wear thickness and height are plotted for each wheel (Figure 4 to 23). The linear trendline is also plotted to observe the wear profile patterns. The gradient of the linear trendline graph is notified as to the wear rate in mm/km. Figure 4 shows the graph of wheel 1R. From the graph, it is shown that the flange thickness drops to 29.05 mm from 31.00 mm at 8889 km mileage. The flange height is however increases from 28.00 mm to 29.23 mm. The mechanism of wheel wear happens when the wheel is in contact with the rail. Since the rail material is harder than the wheel, it forces the wheel to wear first as compared to the rail. This is because it is cheaper and easier to do wheel maintenance and replacement compared to the maintenance and replacement of rail. The wheel wear area is shown in Figure 3. As the wheel is in contact with the rail, the base of the wheel flange suffers from wear. The higher the load, the higher the wear. This eventually increases the flange height and reduces the flange thickness. The vertical load merely due to the weight of the commuter train with passengers is acting downward and causing the wheel wear and increment in flange height. The lateral load or force due to lateral motion of the commuter rail during operation is causing the wheel wear and reduction in flange thickness. The absolute wear rates from the trends in Figure 4 show the values of $|-5 \times 10^{-6}|$ mm/km and 3×10^{-3} mm/km for the flange thickness and height respectively. It can be observed that the trends (Figure 4 to 23) of flange height are increasing and the flange thickness is decreasing as the commuter train mileage of operation is increased. The absolute wear rates for flange thickness is relatively higher than the wear rates of flange height for all the wheels. Even though the vertical load of the commuter train is higher than the lateral force during operation, the vertical load is distributed on a wider length of wheel thickness. Therefore, its effects on wear are reduced. On the other hand, the load distribution on the small length of wheel flange thickness which supports the lateral force is high. This causes the flange thickness to reduce at a higher rate.

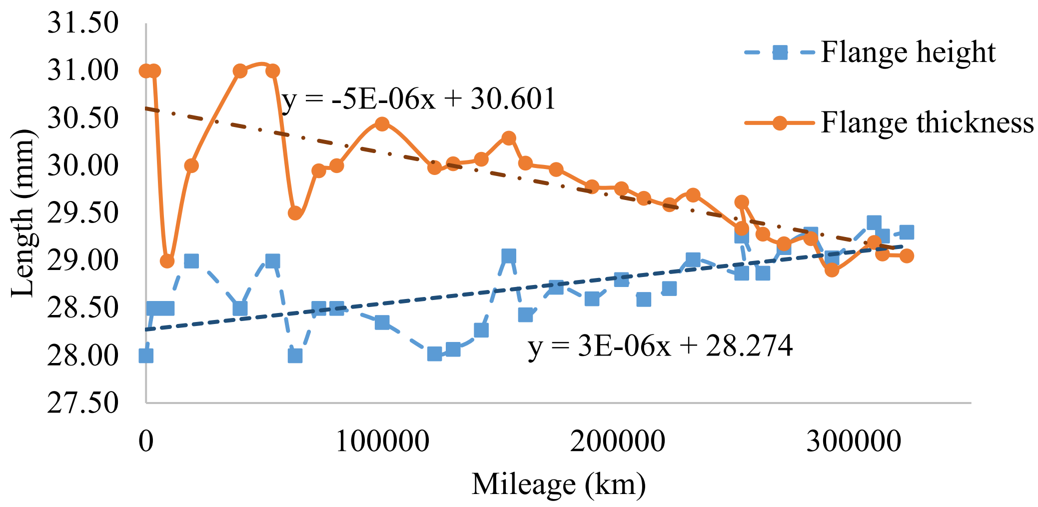

Figure 4: Railway wheel profile data for wheel 1R

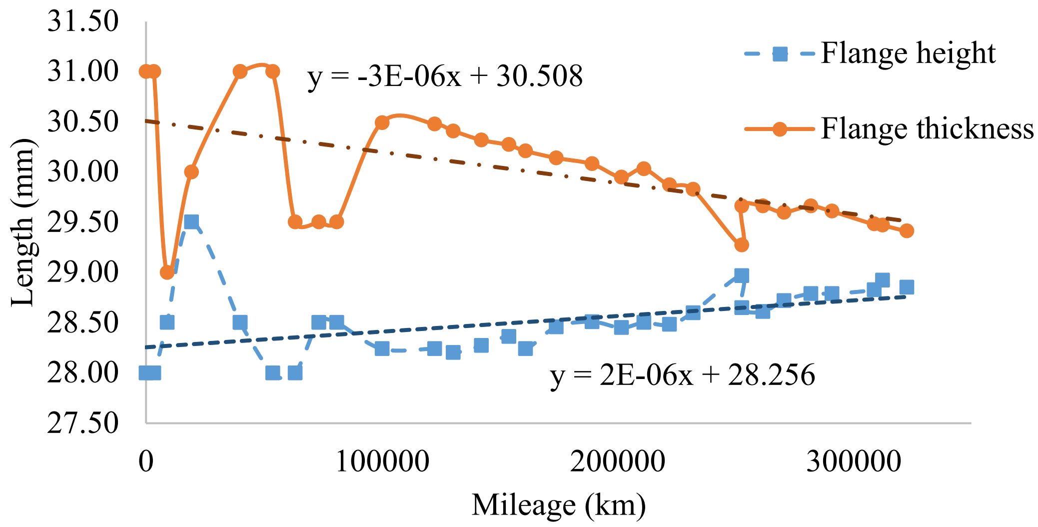

Figure 5: Railway wheel profile data for wheel 2R

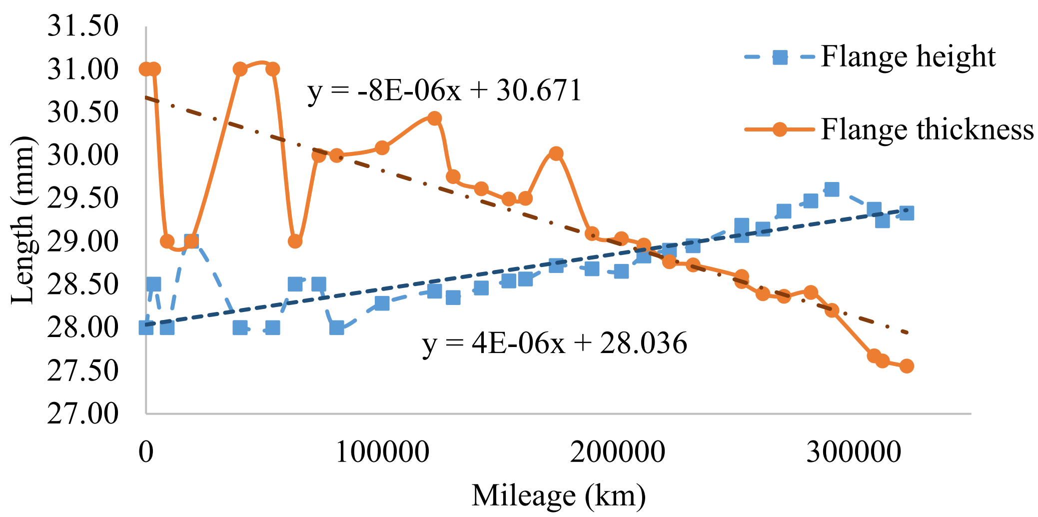

Figure 6: Railway wheel profile data for wheel 3R

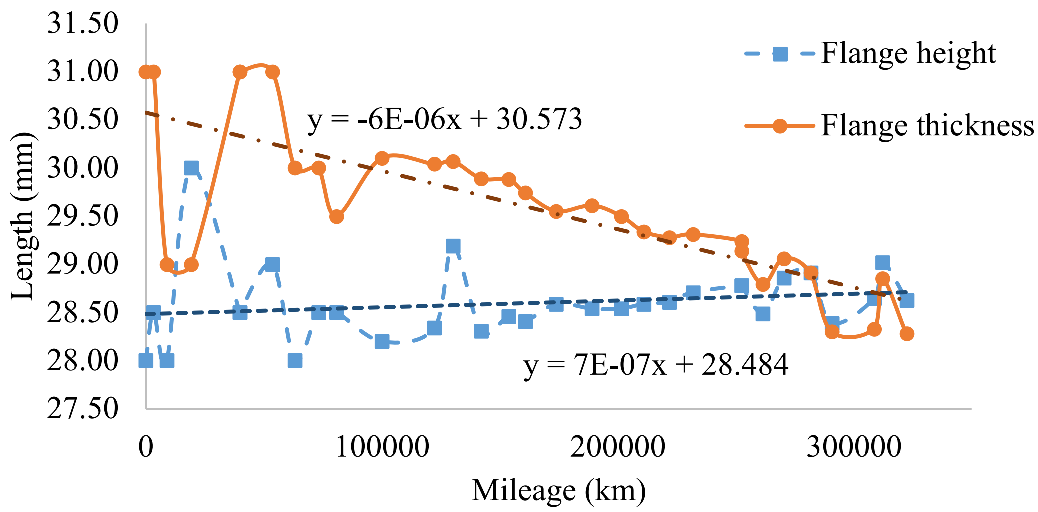

Figure 7: Railway wheel profile data for wheel 4R

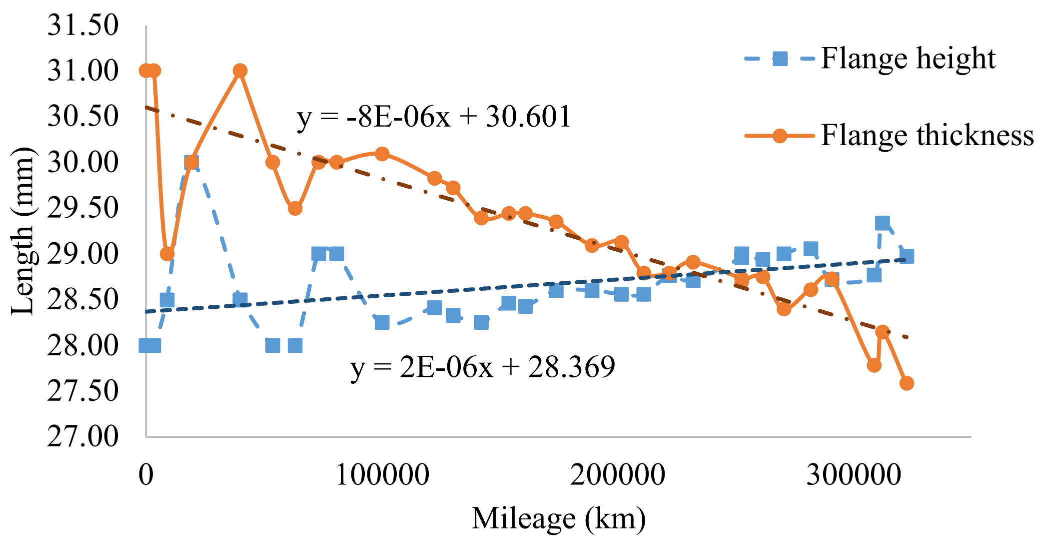

Figure 8: Railway wheel profile data for wheel 5R

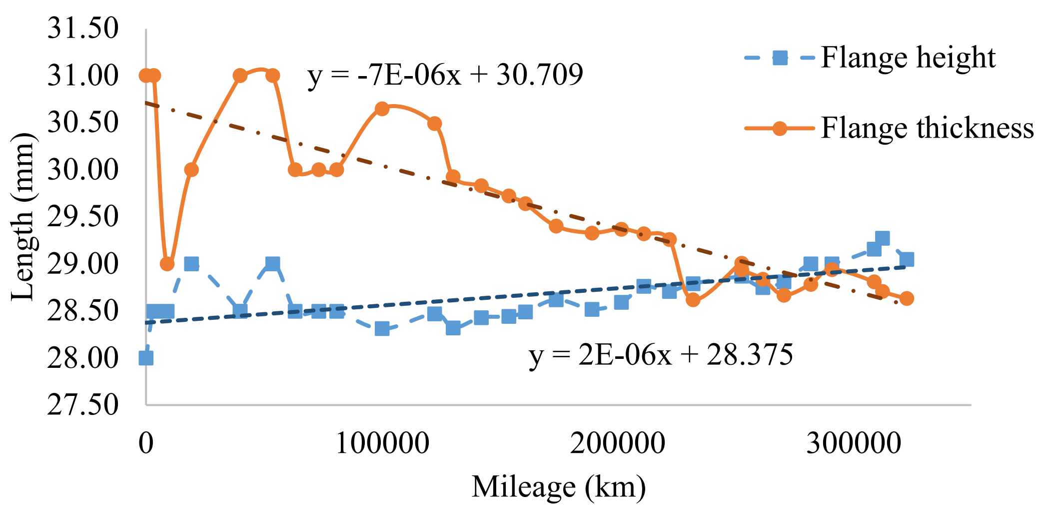

Figure 9: Railway wheel profile data for wheel 6R

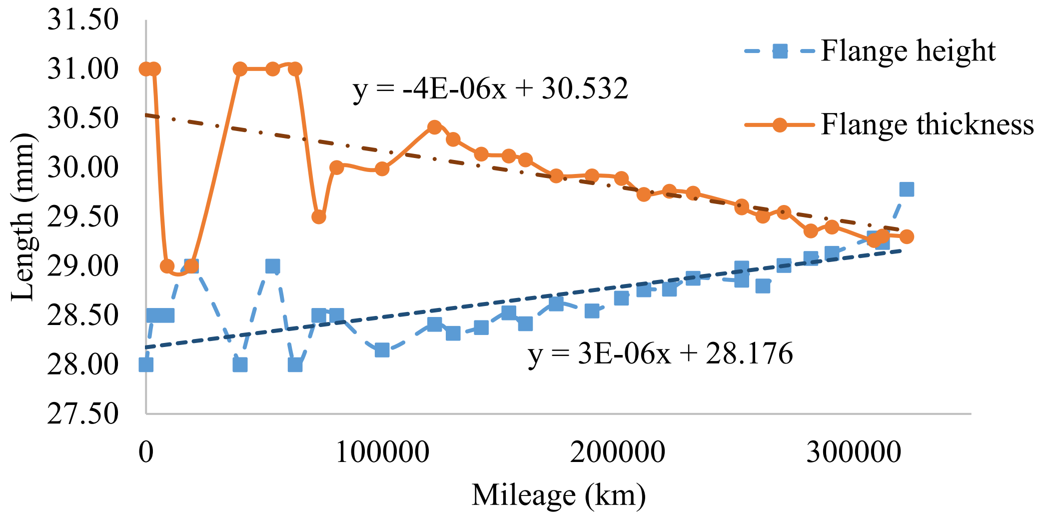

Figure 10: Railway wheel profile data for wheel 7R

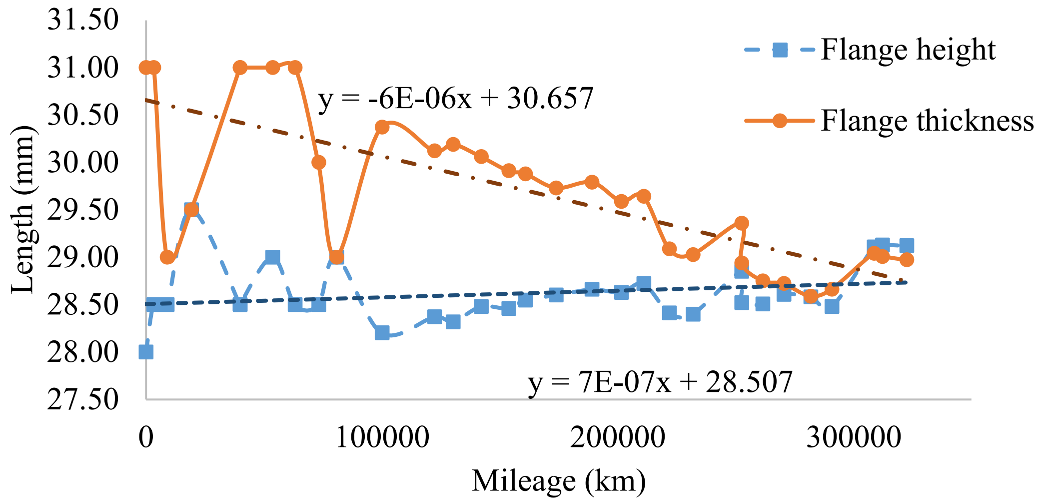

Figure 11: Railway wheel profile data for wheel 8R

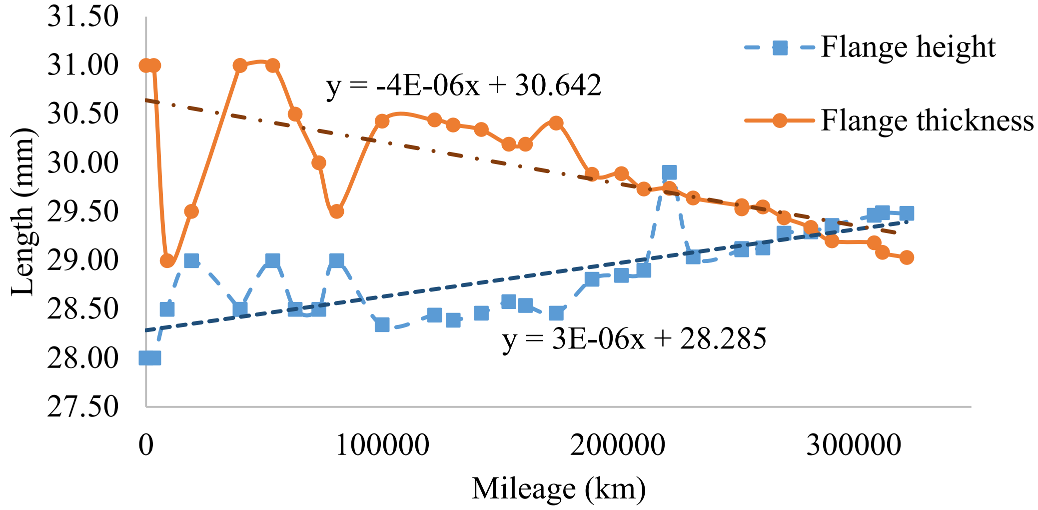

Figure 12: Railway wheel profile data for wheel 9R

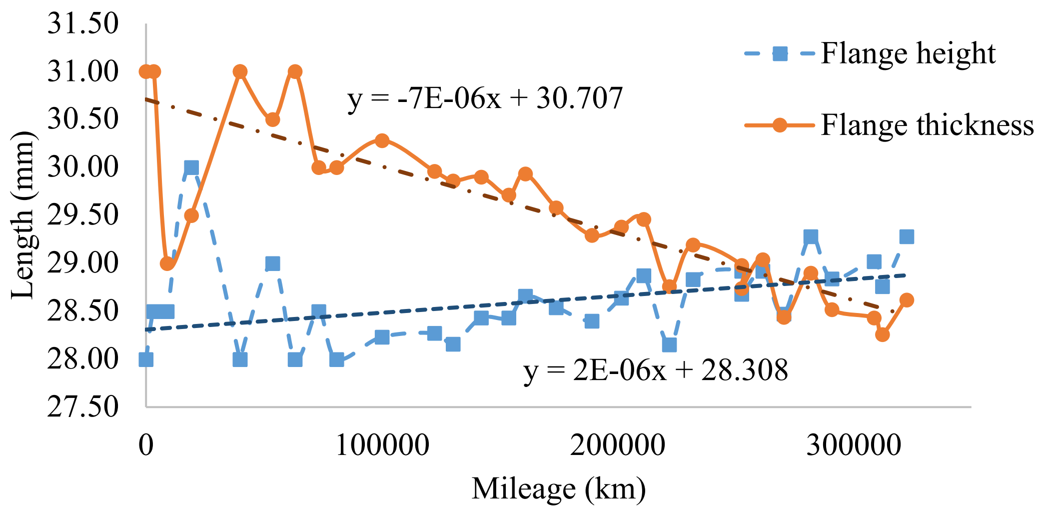

Figure 13: Railway wheel profile data for wheel 10R

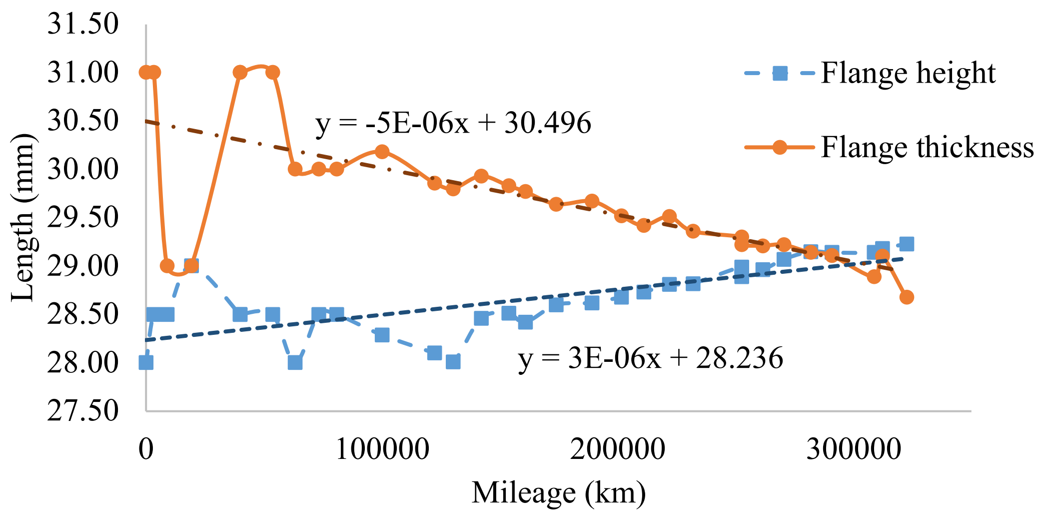

Figure 14: Railway wheel profile data for wheel 1L

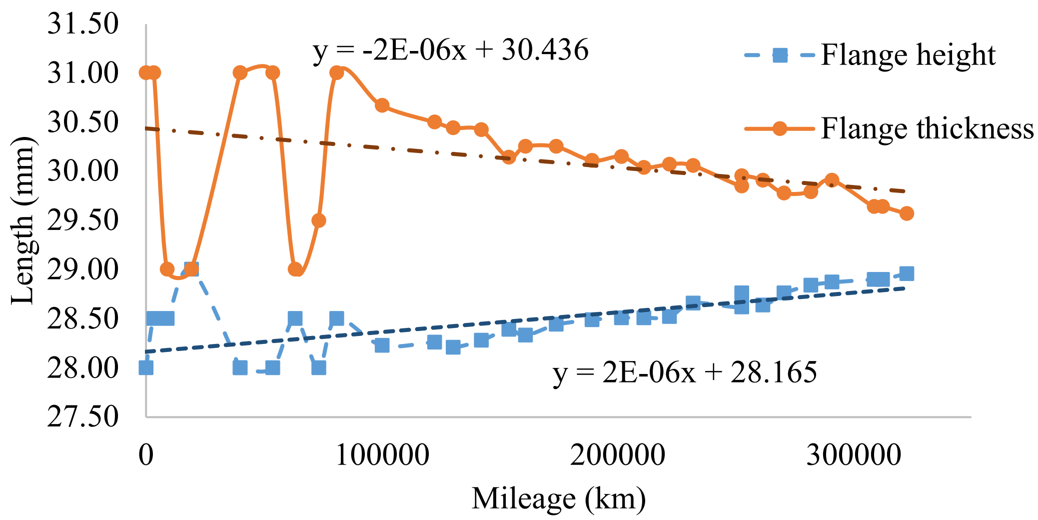

Figure 15: Railway wheel profile data for wheel 2L

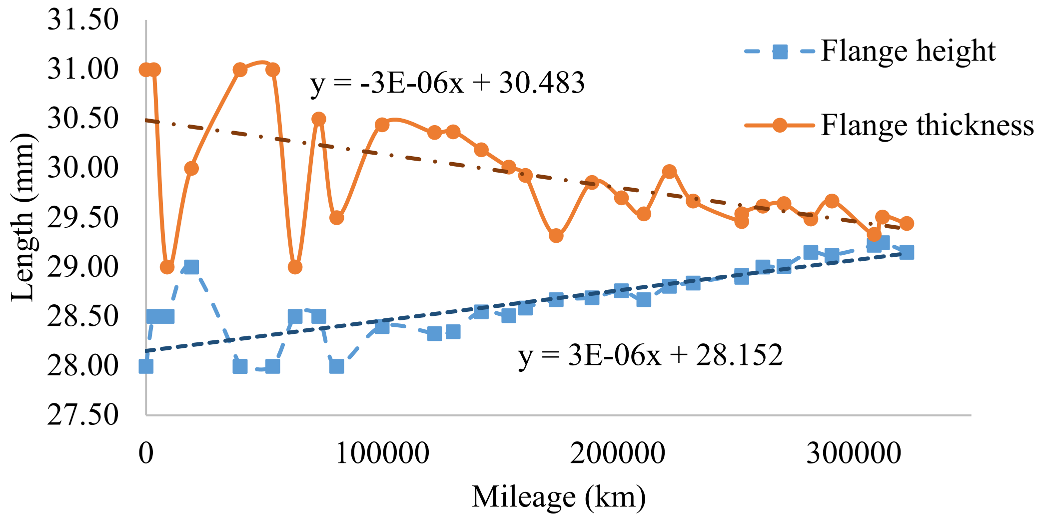

Figure 16: Railway wheel profile data for wheel 3L

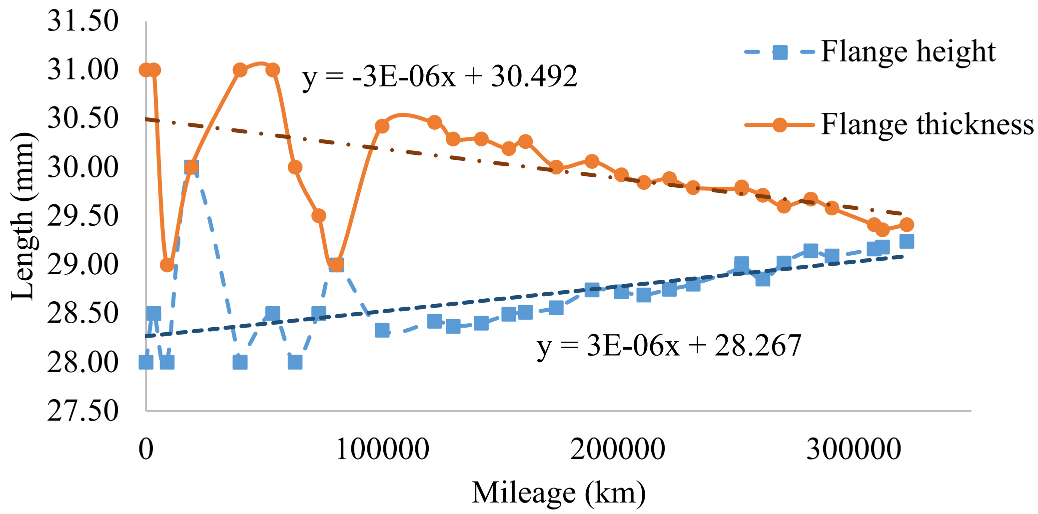

Figure 17: Railway wheel profile data for wheel 4L

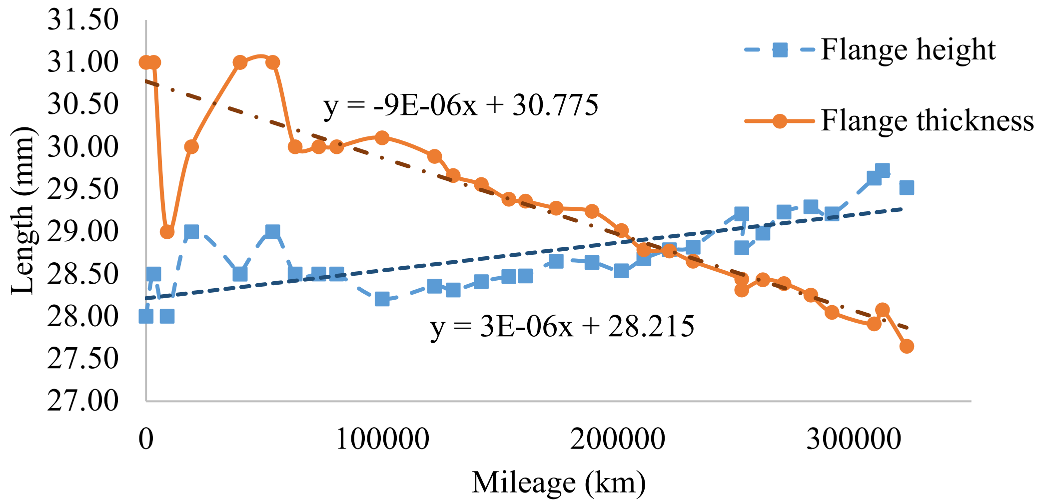

Figure 18: Railway wheel profile data for wheel 5L

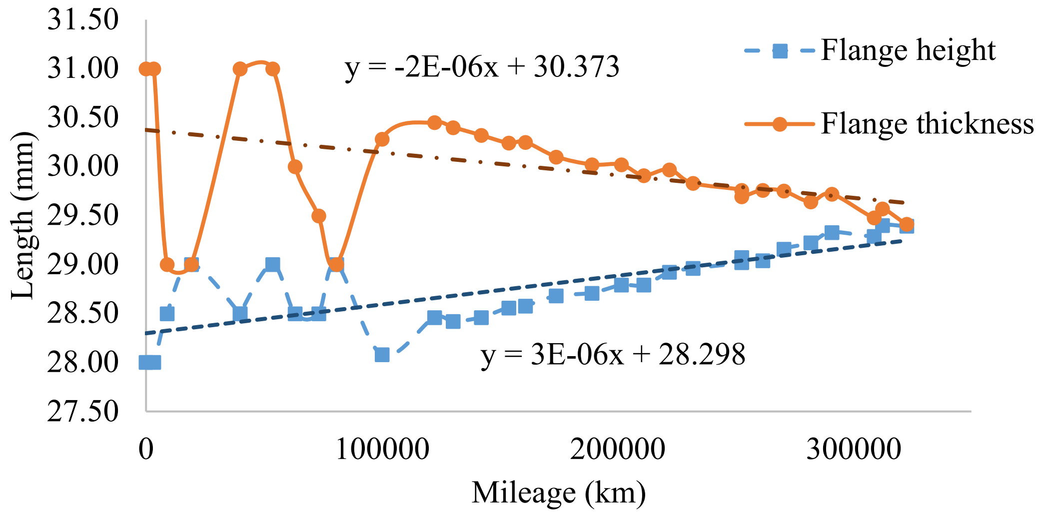

Figure 19: Railway wheel profile data for wheel 6L

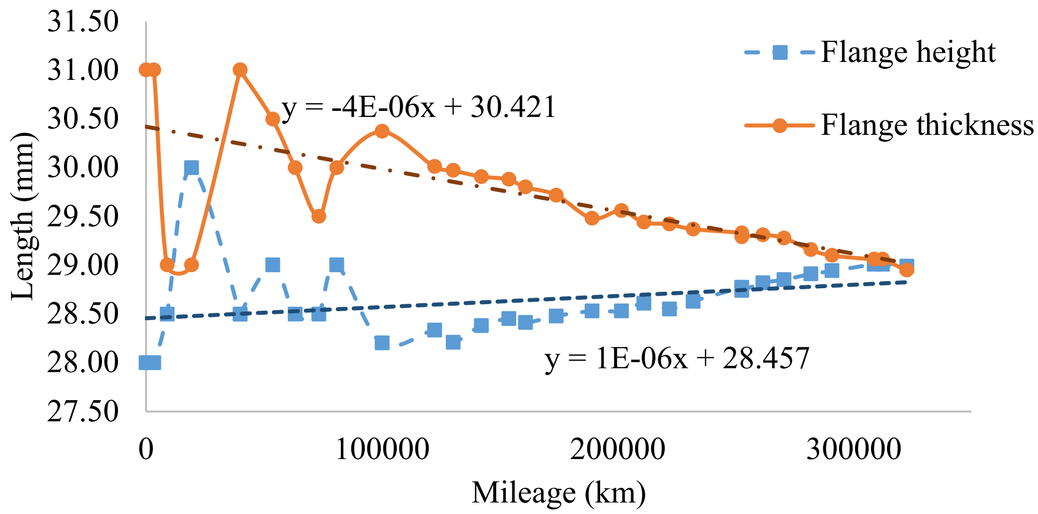

Figure 20: Railway wheel profile data for wheel 7L

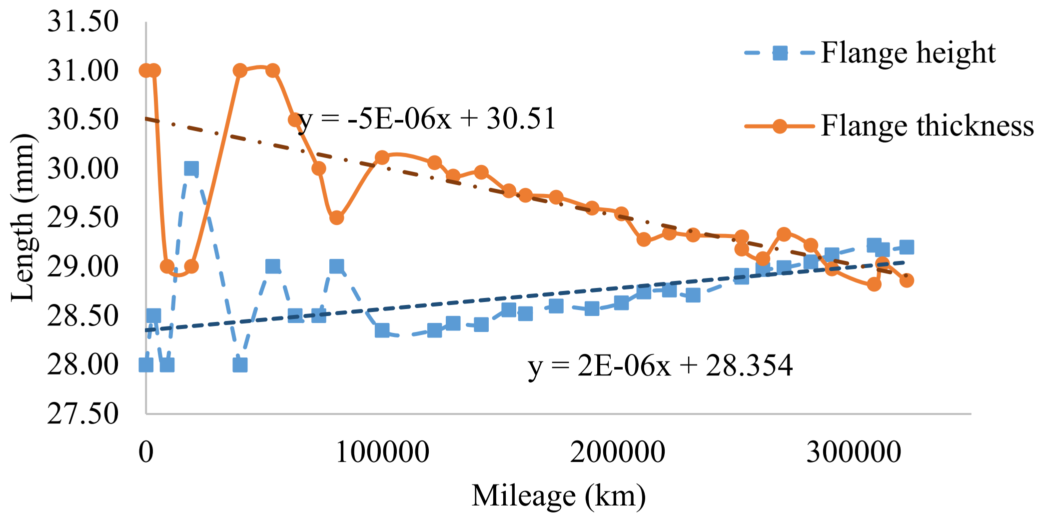

Figure 21: Railway wheel profile data for wheel 8L

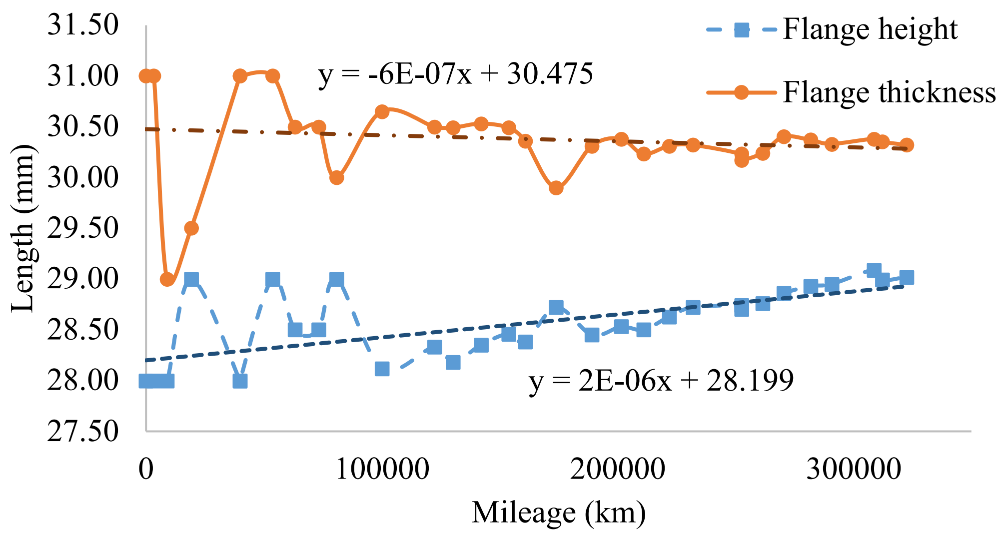

Figure 22: Railway wheel profile data for wheel 9L

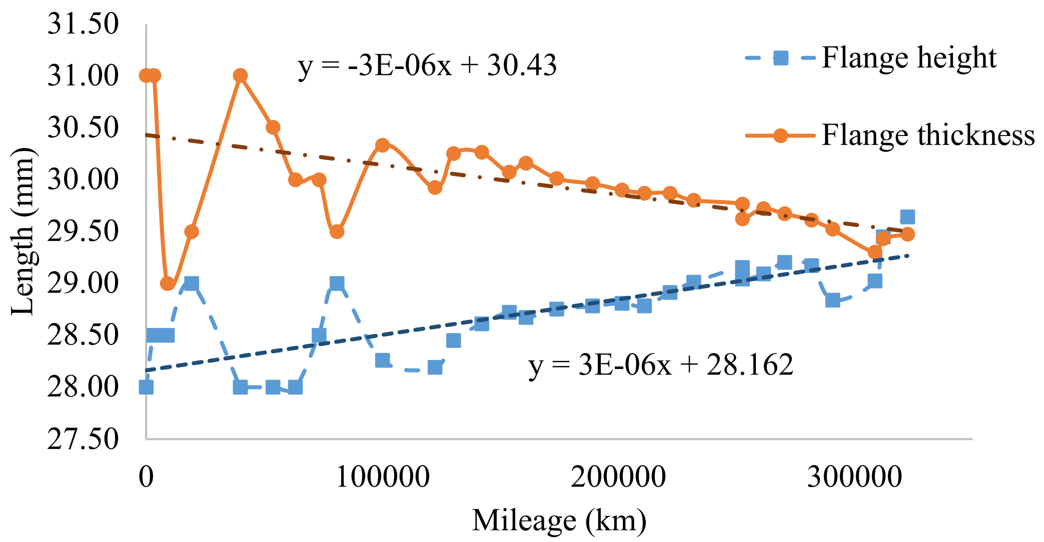

Figure 23: Railway wheel profile data for wheel 10L

Table 5 tabulates the wear rates of the flange height (M_H) and thickness (M_T). The average wear rates for the right wheel are 2.24 x 10^{-6} mm/km for M_H and 5.80 x 10^{-6} mm/km for M_H. For the left wheel, the average wear rates are 2.50 x 10^{-6} mm/km for M_H and 4.20 x 10^{-6} mm/km for M_H. These show that the wheels need to be operated for mileage of more than 50 000 kilometers to achieve 1 mm of wear or reduction in thickness or increment in height which requires the wheels to be reprofiled or cut. The overall average wear rate of M_T is higher than M_H as shown in the same table with values of 5.00 x 10^{-6} mm/km and 2.37 x 10^{-6} mm/km.

Table 5: Wheel flange wear rates (10^{-6} mm/km)

Wheel	**Right**		**Left**		**Axle (Average)**	
	M_H	M_T	M_H	M_T	M_H	M_T
1	3.0	5.0	3.0	5.0	3.0	5.0
2	2.0	3.0	2.0	2.0	2.0	2.5
3	4.0	8.0	3.0	3.0	3.5	5.5
4	0.7	6.0	3.0	3.0	1.9	4.5
5	2.0	8.0	3.0	9.0	2.5	8.5
6	2.0	7.0	3.0	2.0	2.5	4.5
7	3.0	4.0	1.0	4.0	2.0	4.0
8	0.7	6.0	2.0	5.0	1.4	5.5
9	3.0	4.0	2.0	6.0	2.5	5.0
10	2.0	7.0	3.0	3.0	2.5	5.0
Average	2.24	5.80	2.50	4.20	2.37	5.00

Figures 24 and 25 show the comparison of wear rate between flange height and thickness among the wheels. It is can be observed that the center wheels, wheel 5 and 6 suffer higher wear on the flange thickness compared to the end wheels, wheel 1 and 10. This is due to the load of passengers, where most of the passengers sit and stand filling the center cabins. Since most passengers are in the center part of the commuter train, the vertical load and lateral load acting on the center wheels are significant. This causes the highest wear rate on the center wheels.

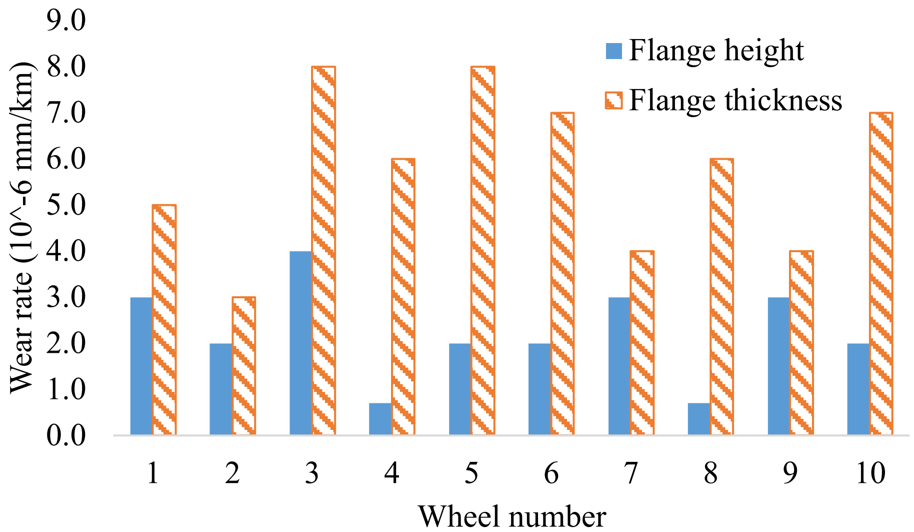

Figure 24: Wear rate of right flange height and thickness

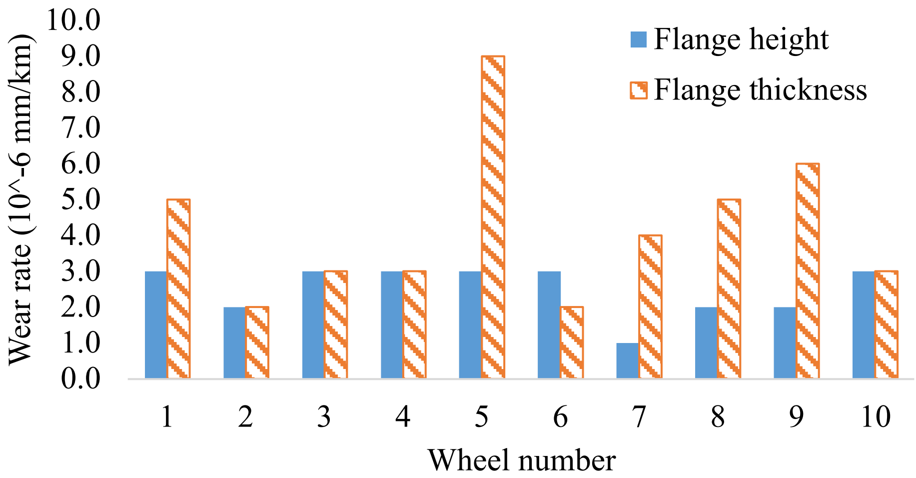

Figure 25: Wear rate of left flange height and thickness

Figure 26 shows the average wear rate of the wheel flange at a different axle. Since the numbering of the wheel is the same as the number of the axle, the trend of wear rate for axle 1 to 10 is almost the same as the trend of wear rate for wheel 1 to 10. The highest wear rate is happening on the center axle wheels which is axle 5. The finding the same, where most of the passengers are boarding on the center of the train for easy and fast train disembarkment.

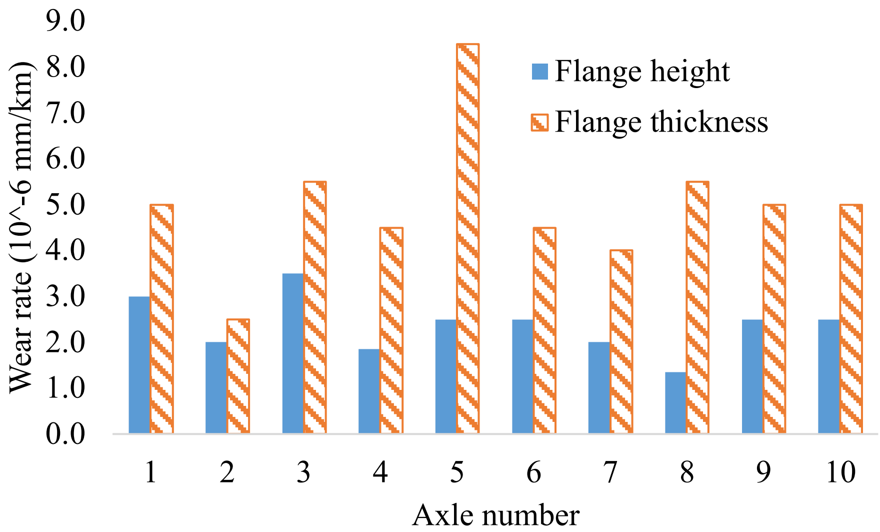

Figure 26: Average wear rate on the different axle

The commuter rail travels from Kuala Lumpur Airport to Kuala Lumpur Sentral and vice versa (Figure 27). It travels about 57 kilometers with a speed of around 140 km/h to 160 km/h.

From the train route design, there are at least three curve tracks with low radius (Figure 27). The first curve track below has quite a large radius roughly within r_1 = 1.4 km. It gives benefits to the train to have enough time to maneuver the track and avoid derailment to happen. The second and third curve track has a radius within $r_2 = r_3$ = 1.3 km. A higher radius is very helpful in improving bogie steering and reducing lateral load. The higher the radius of the track curve, the lower the wear produced on the wheels. Figures 28 and 29 show the comparison of wear rates between left and right wheels. On average, the flange height wear rate, M_H is higher on the left wheels compared to the right wheels. This is because, on the daily basis operation of the train commuter, the train is docking or stopping on the left side of the platform. This means passengers are using the left entrance frequently instead of the right entrance. Therefore, the majority of the passengers standby and standing on the left side inside the train cabin causing higher vertical loads on the left side of the wheels. At high speed, the lateral forces acting on the wheel are high on these curve tracks. When the train commuter starting its route from KLS and ended at KLIA, at these curve tracks, the commuter train is running at a higher speed compared to the opposite direction. At these curve tracks, the bogies are turning to the left, causing the right wheels to support more lateral loads of the train compared to the left wheels. These high lateral loads eventually increase the wear rate M_H of the left wheel higher than the right wheels.

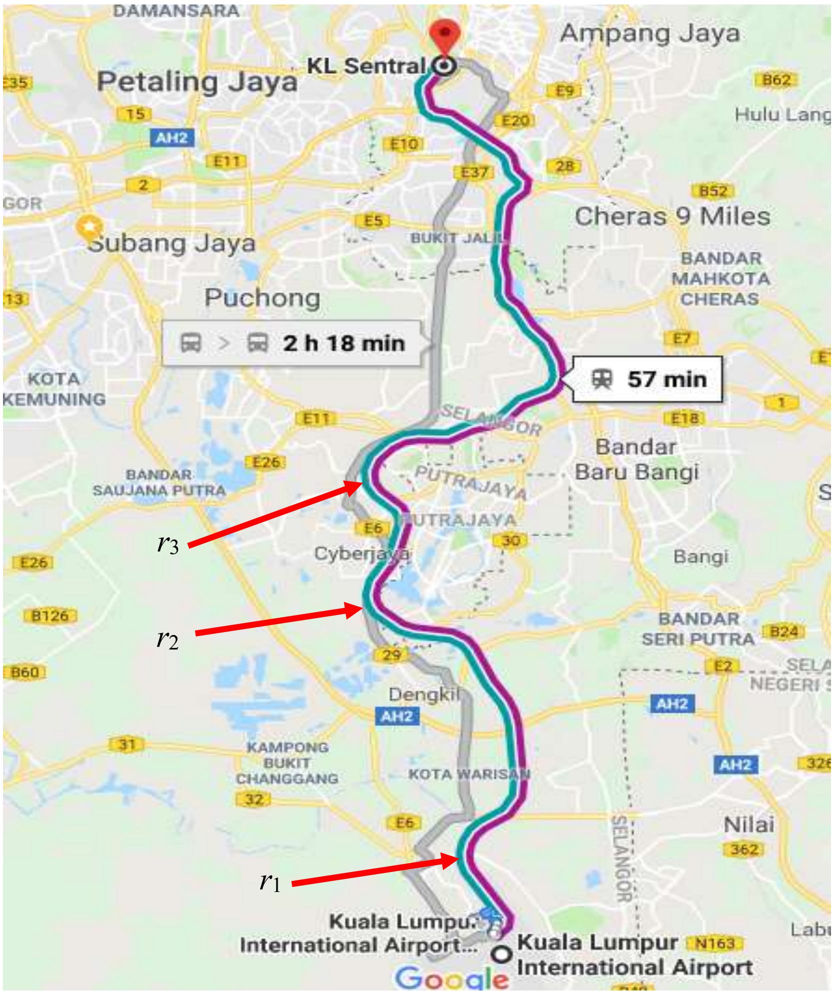

Figure 27: Train route

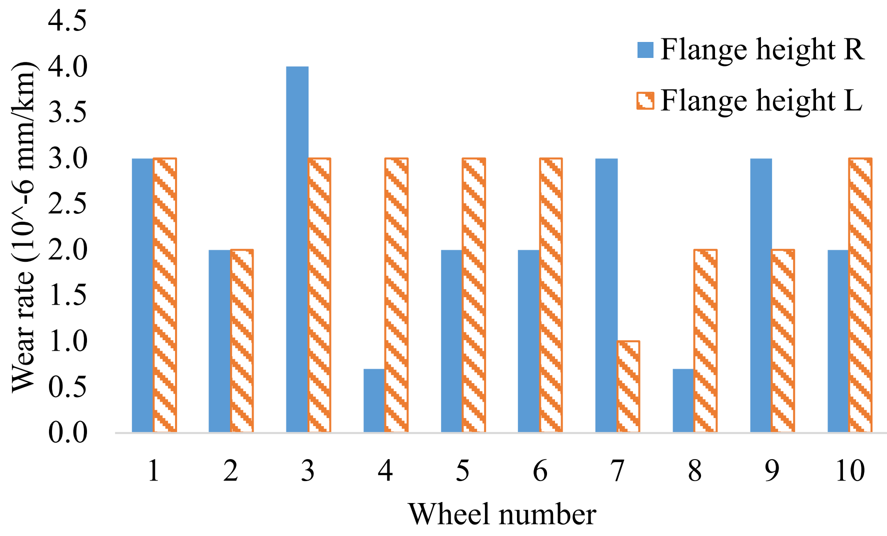

Figure 28: Wear rate of flange height

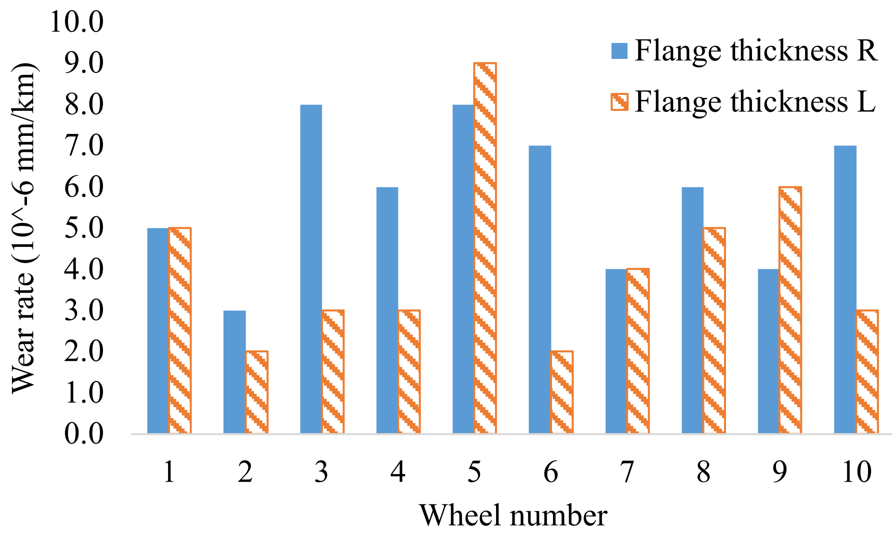

Figure 29: Wear rate of the flange thickness

4.0 CONCLUSION

The analysis of railway wheel flange wear was performed. Overall trends showed that the wheel flange height was increased and the wheel flange thickness was decreased. These were due to the wear mechanism of the wheel-rail contact. The vertical and lateral loads on the wheel were causing wear on the wheel flange base. The higher the vertical load, the higher the wear rate of the flange height (M_H). The higher the lateral load, the higher the wear rate of the flange thickness (M_T). Due to the low vertical load distribution on the wider length of the wheel width as compared to the high lateral load distribution on the narrow wheel flange thickness, the M_H is smaller than M_T. The normal high-speed running operation on the curve tracked turning to the left, increases the lateral load effects on the right wheels. Therefore, the M_T of the right wheel is higher than *the* M_T of the left wheels. The M_H is however higher on the left compared to the right wheels. This is due to the default train-platform disembarkment where most of the time the train is disembarking the passengers from the left side of the train. Therefore, most of the passengers are ready and standing on the left side of the train cabin. The high wear rates on the center's wheels and axles show that most of the vertical load that caused the wheel wears are due to the concentration of passengers riding the train at the center of the vehicle. The wheel flange wear patterns and wear rates can be used for preventive maintenance of the wheel for wheel reprofiling and replacement. The rotation of wheel position can also be applied to optimize the wheel application.

5.0 ACKNOWLEDGEMENT

The authors are gratefully and acknowledge the support received from the Al-Furat Al-Awsat Technical University, Technical College Al-Mussaib, Babylon, Iraq, Centre for Advanced Research on Energy (CARe), and Universiti Teknikal Malaysia Melaka, Malacca, Malaysia, as well as the financial support provided by the Short Term Research Grant, Grant no. PJP/2010/FKM(9B)/S00655, Fundamental Research Grant Scheme (FRGS), Grant no.: FRGS/2010/FKM/TK03/5/F00080, and ERL Maintenance Support Sdn. Bhd., Selangor, Malaysia.

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