Demiryolu Mühendisliği Railway Engineering
Ocak 2023 Jan. 2023
Sayı:17, Sayfa: 107-114 Issue:17, Page: 107-114
Araştırma Makalesi Research Article
doi: 10.47072/demiryolu.1166068
http://dergipark.org.tr/demiryolu
e-ISSN: 2687-2463, ISSN: 2149-1607

Investigation of Tribological Properties of Head, Web and Foot Sections of R260 Rail

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(Alınış/Received: 23.08.2022, Kabul/Accepted: 08.11.2022, Yayımlama/Published: 31.01.2023)

Abstract: It is important to know tribological properties of rail and wheel for predicting the service life of both components. In railway, the tribological system is open and the harsh working condition can be seen as the contact stress between rail and wheel is extremely high. The behaviour of the tribological system varies depending on the chosen rail-wheel materials and also third body (water, humidity, lubricant, debris and combination of these elements). The coefficient of friction and wear resistance are strongly dominated by chosen material and its properties. Up to now, a number of researchers focused only on the tribological properties of the head of rail material. Recent experimental study has devoted to investigate the tribological properties of head, web and foot sections of R260 rail, as the mechanical properties of rail changes from the head to the foot of rail. Different sections of R260 rail have been evaluated in terms of microstructural, hardness, tribological and wear resistance properties. According to obtained results of the ball-on-disc wear tests, the highest wear resistance belongs the head of R260 rail as expected. The coefficients of friction of the web, head and foot of R260 have been found as 0.39, 0.35 and 0.38, respectively.

***Keywords**:* Rail wear, Tribology, Rail material

R260 Rayının Mantar, Gövde ve Taban Kısımlarının Tribolojik Özelliklerinin Araştırılması

Öz: Ray ve tekerleğin hizmet ömrünü tahmin etmek için her iki bileşenin tribolojik özelliklerini bilmek önemlidir. Demiryolunda tribolojik sistem açıktır ve ray ile tekerlek arasındaki temas gerilimi son derece yüksek olduğundan zorlu çalışma koşulları görülebilir. Tribolojik sistemin davranışı, seçilen ray-tekerlek malzemelerine ve ayrıca üçüncü cisme (su, nem, yağlayıcı, kalıntı ve bu elemanların kombinasyonu) bağlı olarak değişir. Sürtünme katsayısı ve aşınma direnci, seçilen malzeme ve özellikleri tarafından güçlü bir şekilde kontrol edilir. Bu zamana kadar, bir dizi araştırmacı sadece ray mantar malzemesinin tribolojik özelliklerine odaklanmıştır. Bu deneysel çalışma, rayın mekanik özellikleri rayın mantar kısmından tabanına doğru değiştiği için, R260 rayının mantar, gövde ve taban bölümlerinin tribolojik özelliklerinin araştırmasına adanmıştır. R260 rayının farklı bölümleri mikro yapısal, sertlik, tribolojik ve aşınma direnci özellikleri açısından değerlendirilmiştir. Disk üzerinde bilye aşınma testlerinden elde edilen sonuçlarına göre, beklendiği gibi en yüksek aşınma direnci R260 rayının mantar kısmına aittir. R260 rayının mantar, gövde ve taban kısımlarının sürtünme katsayıları sırasıyla 0.39, 0.35 ve 0.38 olarak bulunmuştur.

***Anahtar kelimeler**:* Ray aşınması, Triboloji, Ray malzemesi

1. Introduction

The most critical element of the superstructure is rail. It has important roles such as supporting and guiding of wheels, ensuring adhesion force and transmitting longitudinal, horizontal and vertical forces. A contact patch between wheel and rail is very small (approximately 100 mm^2) and carries rail vehicles. This contact patch is open system and works under harsh conditions as the normal stresses are very high [1]. Additionally, a rapid temperature increase (normally it is several hundred degrees Celsius but in extreme conditions over 1000 °C) can be seen because of the slip between rail and wheel [2]. Combination of high normal stress and temperature cause inevitable wear not only rail but also wheel. In order to extend the service life of rail and wheel, the tribological system has to be understood well. The behaviour of the tribological system varies

Atıf için/Cite as: F. Bozkurt, "Investigation of tribological properties of head, web and foot sections of R260 rail," *Railway Engineering*, no. 17, pp. 107-114, Jan. 2023, doi: 10.47072/demiryolu.1166068

depending on the chosen rail-wheel materials and also third body (water, humidity, lubricant, debris and combination of these elements). For a non-lubricated 12 MGT railway line, the annual cost per meter of rail maintenance approximately is US$ 54. Total cost is more than US $ 1.5 Million for only 30 km railway line [3].

The friction between wheel and rail is an important parameter and plays a key role in wheel–rail interface. The wear resistance of rail – wheel materials and friction management has been studied extensively by numerous researchers. Bozkurt and Er studied two kind of boron steels as an alternative of R260 rail [4]. The wear tests were performed with twin disc configuration (roller on roller) under dry and wet (water lubricated) conditions. R260 rail steel, AISI 51B60H and 30MnB5 boron steels were tested against disc prepared from ER9 class wheel material (under 5.18% slip ratio, 1.5 GPa contact stress and 200 rpm). They reported that tested both boron steels have exhibited better wear resistance than R260 rail material and showed optimum coefficient of friction values under dry and wet conditions. Ay and Çelik investigated the friction coefficient of rail under different sliding speeds (5, 7.5, 10 and 12 cm/s.) applying 8N load [5]. The specimen is prepared from used rail section. As counterpart WC ball (Ø3 mm) was used. They presented that average coefficient of friction was found to be as 0.38 under dry condition and 0.15 under water lubricated condition. The wear rates of the rails were increased by increasing sliding speeds for both conditions. Çakır and Çelik assessed the wear resistance of rail steel (R350HT) by isothermal bainitic quenching [6]. Wear tests were perfomed by using ball-on-disc configuration (WC ball Ø3 mm, 10 N load). After completion of wear tests, worn profile was measured and wear resistance was compared. Upper and lower bainite were obtained by isothermal hardening. They expressed that the specimen which had lower bainite structure was the best wear resistant group.

Up to now, there is little published information on the tribological properties of the different sections of the rail material. Recent experimental study has documented the tribological properties of head, web and foot sections of R260 rail, as each region has different mechanical properties due to the production method. Different sections of R260 rail have been considered in terms of microstructural, hardness and tribological properties.

2. Material and Methods of Study

In this study, the samples prepared from virgin rail of R260 rail. The chemical composition of R260 rail is given in Table 1. In order to investigate the tribological properties of different sections of R260 rail, the specimens were cut out from the head, web and foot of the rail with suitable machining procedures. During the machining of the rail, the utmost care has been taken not to change of mechanical and microstructural properties. The dimensions of the prepared samples were 10 mm in diameter and 10 mm in depth. All sample was mounted, and the surfaces of the samples were ground with automatic grinding machine (with 320, 500, 800 and 1000 mesh number). At the final stage, all sample was polished with 3 μm diamond solution. The prepared samples were used for microstructural analysis, hardness tests, and wear tests. In order to reveal the microstructure of R260 rail, the polished samples were etched with a 2% Nital etchant.

Table 1. Chemical composition of R260 rail

C	Mn	Si	P	S	Cr	Al	V
0.72	1.054	0.27	0.014	0.031	0.04	0.001	0.001

In order to characterize the tribological properties of material, wear test is effective and simple method. In the literature, many test methods are proposed and conducted. The main aim of these methodologies is predicting the wear life of mechanical components or system and estimating the coefficient of friction (COF). In this study, adhesive wear test was chosen for investigating the tribological properties of R260 rail. The test configuration was ball-on-disc and all test was completed under dry sliding conditions by using CSM tribometer as shown in Figure 1. The counter body was Wolfram Carbide ball (Ø3 mm, E=690 GPa and hardness=91.2 HRA) whose sphericity and compositions were certified. Before the wear tests, the surface of the samples and WC ball were cleaned by alcohol. All adhesive wear test was performed under 10 N load, 2.5 mm wear radius and 40 m distance and 2.5 cm/s velocity. After the adhesion wear test, the profile of the worn area was measured by Mitutoyo SJ-400 profilometer. The measured profile data was imported to Origin Lab software. Finally, the wear volume was calculated by integrating the area of the wear scar. The specific wear rate (k, mm^3/Nm) of different sections of R260 rail was evaluated and compared considering the Archard equation $k=V/(XL)$ where V is the wear volume (mm^3), X is sliding distance (m) and L is the normal load (N). At least three measurements were performed to specify the specific wear rate.

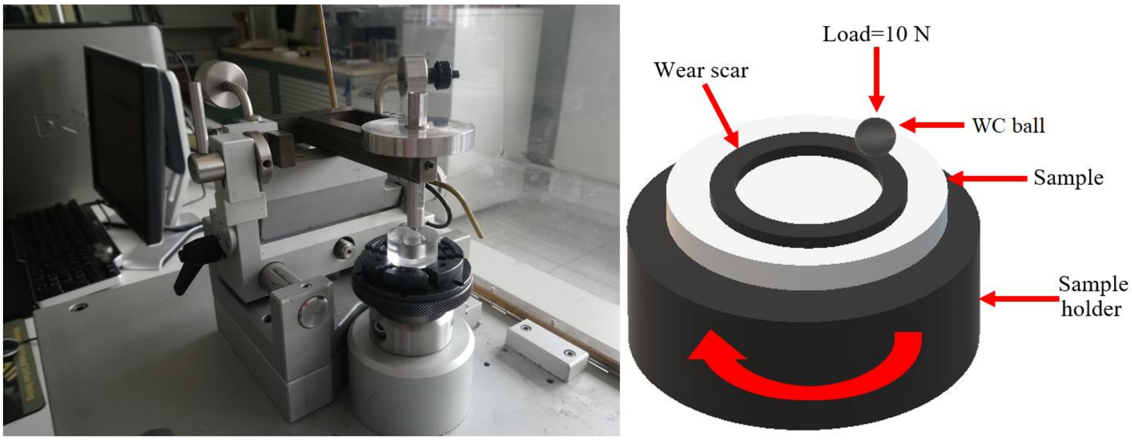


Figure 1. CSM tribometer (right) and schematic illustration of the ball-on-disc adhesive wear test (left)

Hardness test of rail steel is standardized according to EN 13764-1:2011. In this standard, the locations of rail head specified and evaluated according to Brinnel scale. In this study, the hardness of different sections of R260 rail was measured by FM310 microhardness tester. All measurement was evaluated according to ASTM E384 and all results were given in Hardness of Vickers (Hv) scale. All hardness measurement was converted to Brinnel scale.

3. Results and Discussion

3.1. Microstructural Results

The microstructures of head, web and foot of R260 rail are captured by using light microscope at 500x magnification and shown in Figure 2. It is visible that all section of R260 rail has pearlitic microstructure. The directions of pearlite formed in different arrangement. The microstructure of pearlite is lamellar mixture of ferrite and cementite phases. The mechanical properties of rail steel (yield strength, tensile strength, hardness and wear resistance) strongly depend on the ferrite-pearlite ratio, thickness and interlamellar distance of cementite phase [7]. A decrease in the interlamellar distance of cementite results with increasing of hardness value. A higher hardness value increases the wear resistance of the rail steel. In this study, the foot of R260 rail has more ferrite phase in comparison to other sections. It is expected to have a lower hardness value and wear resistance.

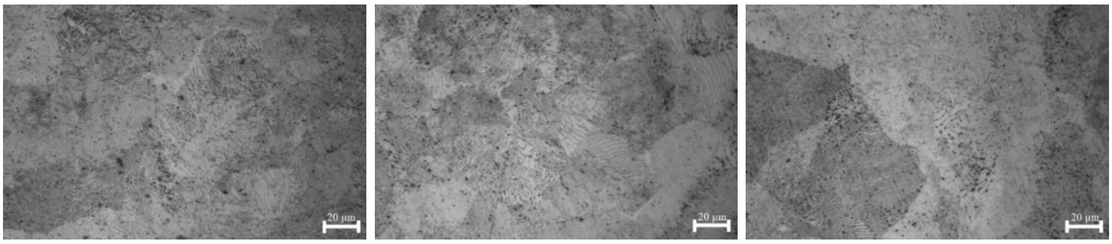


Figure 2. The microstructures of head (left), web (middle) and foot (right) of R260 rail

3.2. Hardness Results

Hardness test method is indication of strength, ductility and wear resistance of materials. Hardness is a measure of resistance to plastic deformation. The rail manufacturing process is complex and needs high technology equipment. The main steps for producing rail are blast furnace, steel making, continuous casting, rolling, straightening and final measurements. In order to increase the wear resistance, the rail is directly taking from rolling mill and transferred to hardening plant at a temperature higher than 800°C. The rail is turned upside down and dipped into the quenching medium resulting to a hardness increase in the entire rail head. After head-hardening process, the cross-sectional hardness distribution of rail should have this characteristic as show in Figure 3 [8]. The hardness of sections of R260 rail was measured at least three times from different locations in Vickers scale as shown in Table 2. The obtained values are converted to Brinnel scale and mean values were considered for comparison. In this study, the average hardness value (in Brinnel) of head, web and foot of R260 rail were found to be 353 HBW, 316 HBW and 278 HBW, respectively. According to EN 13764-1:2011 standard, the hardness values measured shall meet the requirements. For R260 rail steel grade, hardness value should be at least 260 – 300 HBW from specified locations. The hardness value of head section can be slightly higher 360 HBW as the wear resistance of the rail should be higher. With respect to measured hardness values are full accordance with literatures and between the values specified in the standard. The highest resistance of R260 rail section is expected to be head for adhesive wear test.

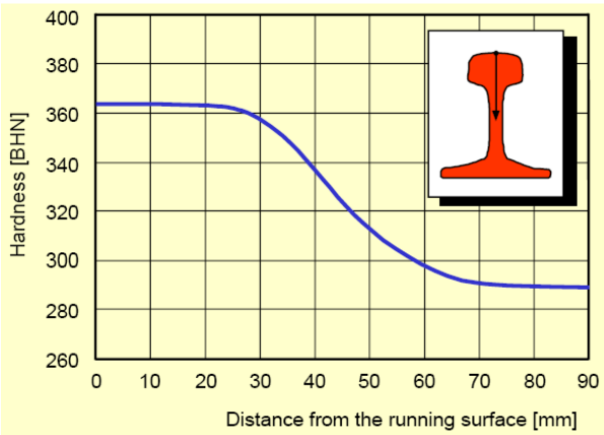


Figure 3. Hardness (in Brinnel) distribution in rails as a function of distance from running surface [8]

Table 2. The hardness values of head, web and foot of R260 rail

	Head			Web			Foot		
Number of measurements	1	2	3	1	2	3	1	2	3
Hardness in Hv	372	374	375	334	336	330	290	296	293
Hardness in Brinnel	352	354	355	317	319	313	275	281	278
Average hardness in Brinnel		353			316			278	

3.3. Tribological Results

Adhesive wear tests were performed by using a WC ball (Ø3 mm) against different sections of R260 rail. Before the starting of the adhesive wear test, considering the literature and to obtain a stable coefficient of friction (COF), pre-tests were conducted to specify test parameters. Under real operating condition in railway, the maximum contact stress between rail and wheel varies from 600 MPa to 2700 MPa [1]. During conducting adhesive wear tests, to simulate extreme loading conditions, the normal load was selected as 10 N and the contact stress was generated as 2.903 GPa. The other adhesive wear test parameter specified as; wear radius 2.5 mm, wear distance 40 m and velocity 2.5 cm/s. All test was completed in dry conditions.

COF vs. distance plot of the different sections of R260 rail steel is shown in Figure 3. All COF vs. distance plot has exhibited two regimes: the running-in and steady state. The transitions from the running-in behaviour to steady state condition had smooth characteristics. In early stages of the wear test, fluctuations were observed for all sample. Approximately 10 m after of starting of the wear test, the steady state regime was observed. The head of R260 rail sample had stable friction curve until the end of the wear test. The web and the foot of R260 rail samples had completed the wear test with some fluctuations as can be seen in Figure 4. In railway, the estimation of friction between the wheel and rail has a critical role. Because it has direct influence on adhesion, wear process, noise generation and rolling contact fatigue. In the literature, COF value fluctuates between 0.5 and 0.7 for dry conditions. Under lubricated conditions, it varies between 0.05 and 0.3 condition. These values were obtained from track or full-scale test rig system. In this study, mean COF (considering stable friction curve) of the web, head and foot of R260 rail were found to be 0.39, 0.35 and 0.38, respectively. Using same methodology (adhesive ball-on-disc wear test) and tribo-couple (rail steel – WC ball), mean COF value was obtained as 0.38 by Ay and Çelik as 0.34 by Çakır and Çelik [5,6]. COF values obtained in this study are in good agreement with literature.

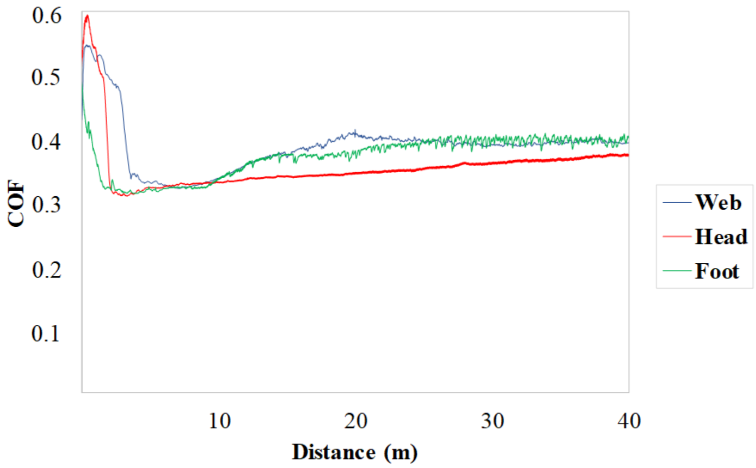
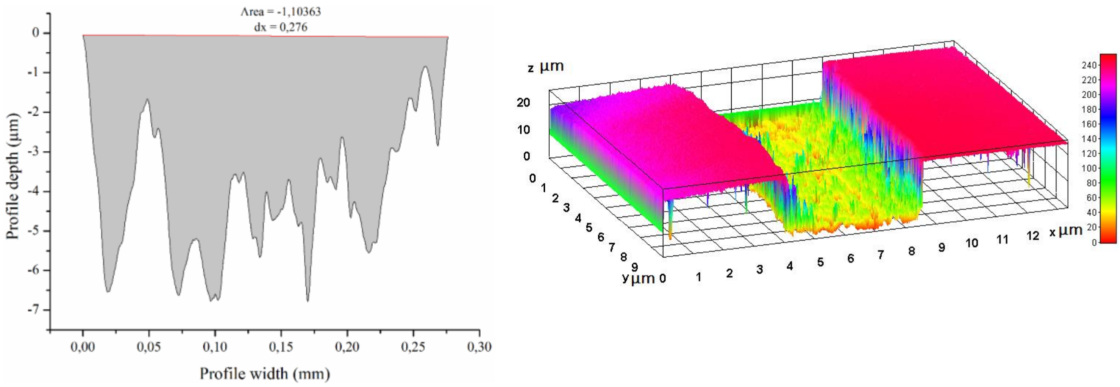


Figure 4. COF vs. distance plot of the different sections of R260 rail steel

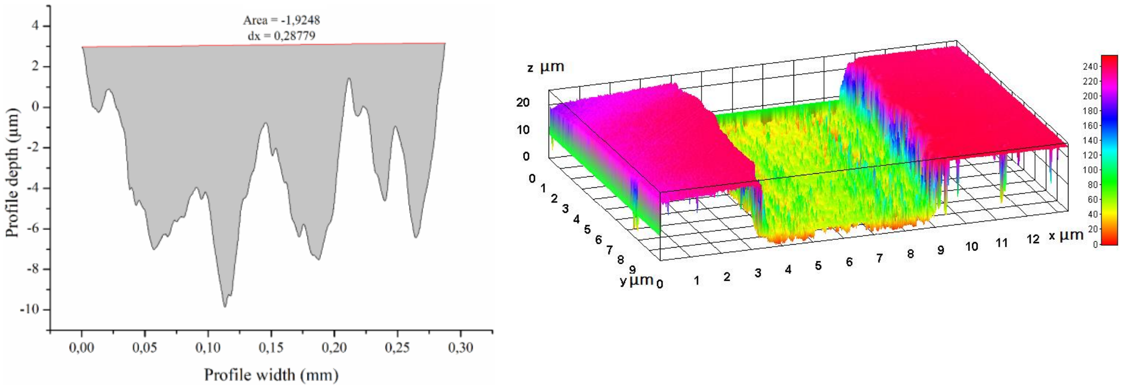
After completion of adhesive wear tests, the profile of worn surfaces was measured by profilometer Mitutoyo SJ-400. The surface profiles were imported to Origin Lab software and the area of worn sections are calculated by integrating. Finally, the wear volume was calculated, and the results were compared considering the specific wear rate (k, mm^3/Nm) for all group sample. In addition to the surface profile of the worn area, 3D surface topography was created by using ImageJ software. Wear track was captured by Nikon Eclipse L150 microscope and imported to software.

In Figure 5, worn profiles and 3D surface topographies of different sections of R260 rail steel are shown. It was found that the minimum area and the volume of the worn sections of R260 rail steel was the head of the rail. This case was expected because the highest hardness value belonged to the head of the rail. It was apparent from Figure 5; the widest wear channel was found for the foot of the rail. The hardness values strongly dominated the worn area of the rail steel. In order to evaluate the results properly, the specific wear rate (k, mm^3/Nm) was also calculated and shown in Figure 6. The results of the specific wear rate were more universal and reliable in comparison to the wear volume loss. The specific wear rates were found to be 2.7591, 4.812 and 7.3575 ($x10^{-6}$, mm^3/Nm) for the head, web and foot of R260 rail, respectively. In summary, the wear resistance was depending on hardness values and each section of rail steel has decreasing wear resistance from the head to the foot region. As a result, it can be said that the hardness values dominate the wear rates.

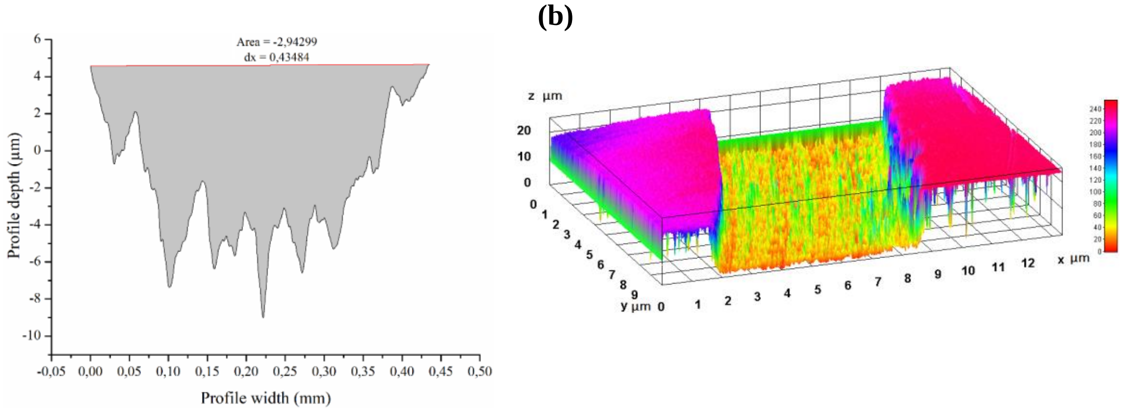
The most critical findings for this study are specific wear rate and coefficient of friction (COF). The specific wear rate is important in terms of useful economic life. The coefficient of friction dominates the wheel–rail interface and the dynamic of rail vehicles.



(a)



(b)



(c)

Figure 5. Profiles and 3D surface topographies of a) head, b) web and c) foot of R260 rail steel

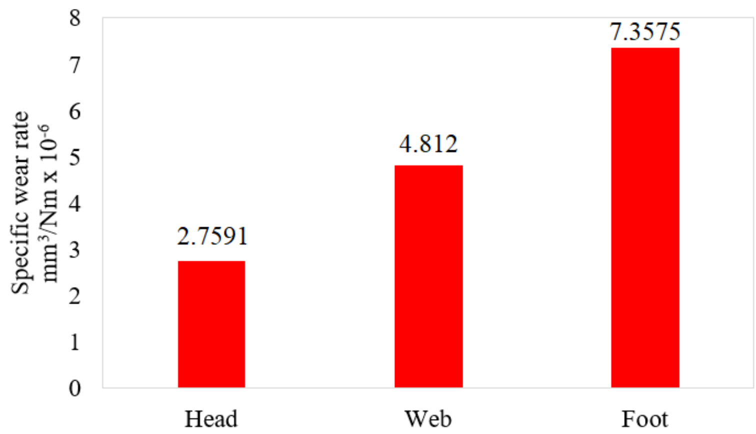


Figure 6. Specific wear rate of different sections of R260 rail steel

4. Conclusion

In conclusion, different sections of R260 rail have been evaluated in terms of microstructural, hardness, tribological and wear resistance properties. The main conclusions can be drawn:

1) The foot section of R260 rail has more ferrite phase in comparison to other regions.
2) The hardness values have decreasing characteristics from the head to the foot of cross sectional of R260 rail.
3) Mean COF of the web, head, and foot section of R260 rail have been close to each other and found to be as 0.39, 0.35 and 0.38, respectively.

4) The most wear resistant section belongs the head of R260 rail as it has the highest hardness value.
5) For future works, different rail-wheel materials can be studied considering various wear test parameters under dry and wet (water, oil and combination of water and oil) conditions.

Acknowledgement

The author acknowledges Eskişehir Technical University and Eskişehir Osmangazi University for providing an opportunity to conduct experiments and The Turkish State Railways (TCDD Taşımacılık) for material supply.

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Resume

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Ethics Statement:
Author confirms that the article is original, there is no plagiarism issue.