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EFFECTS OF FLY ASH ADDITIVE ON THE PROPERTIES OF RAILWAY COMPOSITE DISC BRAKE LININGS

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ABSTRACT

Brake friction materials should satisfy a number of requirements such as stable friction coefficient, low wear rate, environmentally friendly, lightweight, long life, low noise, corrosion resistance and acceptable cost versus performance characteristics.
Fly ash is an important side product, which accumulates in cyclone or electro filters through chimney gases occurring as a result of the combustion of pulverized coal in thermal power plants. In Turkey, approximately 45 million tons of coal is combusted annually and an average of 15 million tons of fly ash is produced. World annual production of fly ash is about 600 million tons. Fly ash which results from the coal-operated power plants causes economic and environmental problems. Fly ash particles are suitable for using in the brake linings of railway as a filler material. Waste fly ashes which contain compositions of Al_2O_3, SiO_2, Fe_2O_3 from thermal power plants are used as brake lining. Many studies have been undertaken to show that adding the environmentally harmful waste to lining material could be used in a cost reducing way.
In this study, the fly ash obtained from coal-fired thermal power plant "Orhaneli and Kemerköy" was used. Our recent study has focused on development and utilization of fly ash for railway frictional composites. Produced composites brake linings contain 40% fly ash in weight ratio from Kemerköy and Orhaneli. We compared the frictional and wear behavior of fly ash reinforced composite brake linings are compared on a commercial railway disk brake lining.
The new developed brake linings have exhibited consistent properties; density of 1,79-2,18 g/cm^3, hardness of 107-112 Hardness Rockwell L (HRL), modulus of elasticity in compression of 376-448 MPa, internal shear strength 15-46 MPa, and coefficient of friction 0,353-0,417.
Keywords: Railway brake linings,tribology,friction, fly ash.

UÇUCU KÜL KATKISININ DEMİRYOLU DİSK BALATA ÖZELLİKLERİNE ETKİSİNİN İNCELENMESİ

ÖZET

Demiryolu kompozit fren balatalarında korozyon direnci, hafiflik, uzun ömürlülük, düşük ses, kararlı sürtünme katsayısına sahip olma, düşük aşınma oranı ve ekonomik özellikleri aranır.
Uçucu kül, termik santrallerde pulverize kömürün yanması sonucu meydana gelen baca gazları ile taşınarak siklon veya elektro filtrelerde toplanan önemli bir yan üründür.Türkiye'de yaklaşık yıllık 45 milyon ton kömür yakılır ve ortalama 15 milyon ton uçucu kül üretilir. Uçucu külün Dünyada yıllık üretimi yaklaşık 600 milyon tondur. Kömürle çalışan santrallerden kaynaklanan uçucu kül ekonomik ve çevresel sorunlara neden olur. Uçucu kül parçacıkları trenler fren balatalarındadolgu malzemesi olarak kullanmak için uygundur. Termik santrallerdeki Al_2O_3 , SiO_2 , Fe_2O_3 bileşikleri ihtiva eden uçucu küller, fren balatalarında kullanılır. Birçok çalışmada çevreye zararlı atık olan uçucu küller , maliyet azaltıcı bir şekilde kullanılabileceğini göstermektedir.
Bu çalışmada, kömür yakıtlı kullanan Orhaneli ve Kemerköy termik santrallerinden elde edilen uçucu küller kullanılmıştır. Bizim çalışmamız demiryolu balatalarında uçucu küllerin kullanımı üzerine odaklanmıştır. Geliştirilen kompozit balatalar ağırlıkça %40 oranında Orhaneli ve Kemerköy uçucu külleri içermektedir. Geliştirilen kompozit balatalar sürtünme ve aşınma performansı davranışları ticari demiryolu balatalarla karşılaştırılmıştır.
Geliştirilen balataların yoğunluğu 1,79-2,18 g/cm^3, sertliği 107-112 HRL, elatik basma modülü 376-448 MPa, iç kesme dayanımı 15-46 MPa, and sürtünme katsayısı 0,353-0,417 aralığında bulunmuştur.
Anahtar Sözcükler: Demiryolu Disk Balata , Triboloji, Sürtünme, Uçucu Kül.

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1. INTRODUCTION

Brake mechanism which is used for slowing or halting a moving object or a machine at work are an indispensable part of systems. Even though the materials and systems used in brakes, which have had a place in almost all vehicles since the beginning of transportation activities, have changed, the main principle remains the same. Movement becomes slower when the brake is engaged[1].

Brake linings are one of the most important safety and performance components of railway vehicles. Brake linings composite materials are distinguished metallic, semi-metallic, composite and carbon-based[2]. Most of the brake linings are typically a composite of a number of different materials. Many of brake linings are composite materials which contain more than 15 different components. These components are binders, reinforcements, friction modifiers and fillers[3].

Fly ash remaining after the combustion of coal in thermal power plants is inorganic residues. Fly ash is composed of glassy, spherical particles, irregularly shaped and with the average grain size of 50 µm - 150 µm. Fly ash has low specific gravity in the range of 1–3 g/cm^3. Fly ash particles are created at high temperatures like 1000-1100 ^oC at thermal power plants chimney. Therefore fly ash is used as composite disc brake linings for providing a thermal stability. The main components in the fly ash: SiO_2, Al_2O_3, Fe_2O_3 ve CaO, MgO, alkali oxides unburned carbon and trace amounts of titanium, phosphorus, beryllium, manganese and molybdenum compounds[4].

V. M. Malhotra et al. examined the effect of the addition of fly ash as friction member composite compositions. 20% by mass of the addition of fly ash to reduce torsion resistance but then fly ash ratio is seen to have improved in resistance by increasing. They also concluded that the use of fly ash in the composite brake pads increases the coefficient of friction the behavior of ash particles was similar to abrasives like Al_2O_3, Cr_2O_3 ve SiC[5]. Samrat Mohanty and Y.P. Chugh have prepared the brake pad mixture containing fly ash over 50%. They produced high homogeneity of composite brake pads and consequently had good braking performance purposes[2]. Bhabani K. Satapathy et al. produced 8 different formulations for composite brake pad which contain 55% and 75% fly ash. They obtained the friction coefficient of 0.269 to 0.386 [6]. Nandan Dadkar et al. produced 4 types of lining materials with aramid fiber containing novolac type phenolic resin which contains 65% - 80% fly ash[7]. K. W. Hein and P. Filip said that formulating brakes test samples, which included up to 25wt% of fly ash, outperformed the commercially available original brake pads in full-scale automotive dynamometer tests[8]. N. Dadkar have examined the performance characteristics of five types of composite friction brake pads which included fly ash and rock wool[9]. The friction effect of vermiculite on the performance is investigated for the brake pads of class F fly ash by Bhabani K. et al.[10]. Fly ash composite brake pads studies were carried out by non-linear regression optimization technique[11]. Aramid fiber, potassium titanate and interaction are a study investigating the effects of the frictional properties for composite brake pads[12]. Handa and Kato studied the effect of the relative amounts of copper powder, cashew dust, and barium sulfate on wear rate and fade using a simplified formulation containing five ingredients and the friction test was performed by a pad-on-disk type tester. The results from a simplified formulation using a pad on disk type tester, however, often show different friction characteristics compared with the results from dynamometer tests or in vehicle tests when commercial friction materials were used [13].

2. MATERIAL AND METHODS

2.1. Characterization of Fly Ash Particles

The thermo gravimetric analyses (TGA) curves indicate the weight change of brake pads as a function of temperature. The fly ash particles samples received from Orhaneli and Kemerköy were tested with the help of TGA and differential scanning calorimetry (DSC). The TGA procedure monitored the weight of the respective samples as a function of temperature. The purpose of DSC testing was to determine the heat flow into material sample as a function of temperature. The samples were tested for the temperature range of 0–600 ^oC in Argon gas atmosphere. DSC measurements were carried out at a heating rate of 5 ^oC /min from 20 ^oC to 600^oC. For DSC measurements, samples were prepared by shaving approximately 10 mg from the injected samples and sealed in aluminum pans.

2.2. Sample Preparation

The weight percentage range of all the components is presented in Table 1.

Table 1. The formulation of components used in the composite disc brake lining

Component	Weight Ratio%	
	F9 (Orhaneli)	F10 (Kemerköy)
Fly Ash	40	
Binder (Phenolic resin)	18	
Fiber (Glass fiber, aramid pulp,rock wool)	6	
Filler($BaSO_4$, $CaCO_3$)	17	
Friction Modifier (Petroleum coke, graphite)	19	

All the mixed components were weighed using Table1 and mixed using a commercial blender with special stirrer apparatus. The mixtures were pressed 150 MPa at a constant temperature of 150^oC for 10 minutes.

F9 F10

Figure 1. Developed samples brake linings

The fly ash used in this study was obtained from a coal-fired power plant in Kemerköy and Orhaneli. Chemical components of the fly ash are presented in Table 2.

Table 2. Chemical components of the fly ash from Orhaneli and Kemerköy

Ccomposition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	PbO	ZnO	CuO	Cr_2O_3	NiO	MnO	(S+A+F) $SiO_2+Al_2O_3+Fe_2O_3$
Orhaneli F9	54	28.7	9.05	4.04	-	2.1	-	0.55	1.1	-	-	-	0.049	0.03	0.04	91.75
Kemerköy F10	27.39	15.57	5.39	30.04	2.43	1.9	0.42	0.46	15.51	0.02	0.02	0.01	0.03	0.02	0.03	48.35

2.3. Friction and Wear Tests

Friction and wear characteristics were investigated using a friction coefficient test rig (according to JIS D 4411). Friction tests were carried out at the temperatures between 100 ^oC and 350 ^oC. The weight and thickness of the samples were noted before and after the friction test to calculate the total wear of each sample.

The friction and wear performance of the braking materials was examined using a constant speed friction tester using a JIS D 4411 friction tester (Wanda Mechanical Co. Ltd.) with a speed of 480 r/min and constant pressure of 0.98 MPa. As a rotor, the disc made of cast iron (grade HT250 with Brinell hardness in the range of 180–220) was used. During the friction test performed at selected temperatures (100, 150, 200, 250, 300 and 350 °C), the data of friction coefficient μf(i) (under the heating conditions) and μr(i) (under the cooling conditions) were obtained.

The friction coefficient of the friction material changes as functions of numerous tribological parameters such as applied pressure, speed, temperature, and humidity. Therefore, The friction coefficient for a commercial friction material is indicated as a code representing a range of friction coefficient according to the Society of Automotive Engineers (SAE) recommended practice[14].

2.4. Hardness Measurements

Surface hardness of new developed brake linings and commercial brake linings was measured using a Rockwell hardness test method (HRL). Rockwell hardness HRL test method consists of indenting the test material with a hardened 6.35 mm (1/4”) steel ball indenter. The indenter is forced into the test material under a preliminary minor load 10 kgf, major load 50 kgf and total load 60 kgf. Before measuring the hardness, surfaces of the specimens were polished using abrasive paper. At least three replications of hardness test for each specimen were made and the average value was reported in Table 5.

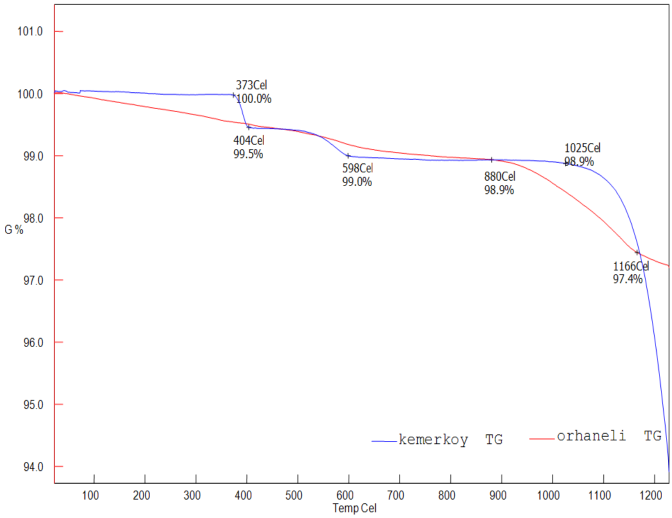
3. RESULTS AND DISCUSSION

3.1. TGA and DSC Results of Fly Ash

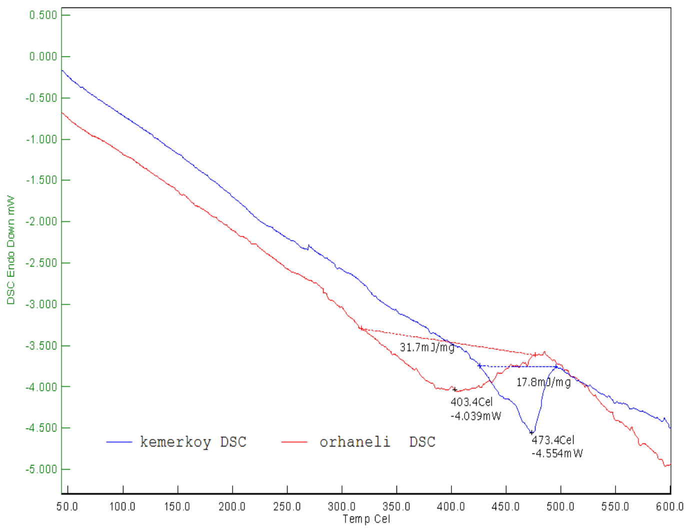
The TGA and DSC data are presented Figure 2. As shown in these Figure, the Kemerköy fly ash particles undergo three distinct phase transitions, in terms of material loss and heat flow behavior, as the temperature is increased. But Orhaneli fly ash particles exhibits a good thermal stability even up to 1200°C. Kemerköy fly ash loses weight drastically between 1100°C and 1200°C. Orhaneli fly ash loses weight drastically between 900°C and 1200°C.

The temperatures at which material transition/loss is initiated are known as onset temperature, and in case of Kemerköy fly ash the one onset temperature is 473 °C. The DSC thermogram of fly ash is smooth until 403 °C and 473 ° C. Sample weight loss, obtained from TG data, was calculated as 6% for the Kemerköy fly ash sample. The fly ash from Kemerköy showed distinct exothermic reactions at 403 °C. At present, it is difficult to determine the exact mechanism of the 403°C exothermic peak. As volatile materials present in fly ash are not expected to play a major role in the overall friction process, they may be suitable for being used as brake lining filler from a physico-thermal point of view. DSC and TG results will be different due to the chemical components of the fly ash, which are S+A+F (SiO_2+Al_2O_3+Fe_2O_3) Fly ash contains some natural sources of ceramic materials such as silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3).

Fly ash particles composed of quartz, mullite, hematite, silica and other metal oxides. Fly ash can improve various properties of matrix materials including stiffness,strength and wear resistance. Figure 3 and Figure 4 shows scanning electron micrographs of fly ash. Fly ash composed of fine sized particles (mean particle size of 50-150 μm) was reported in Table 3. Fly ash particles are typically generated above 1000 ^{o}C, therefore fly ash can be expected to provide thermally stable bulk at high temperature environment, which is a highly desirable characteristic for friction composite materials.



a)



b)

Figure 2. TGA (a) and DSC (b) results of fly ash obtained from Orhaneli and Kemerköy

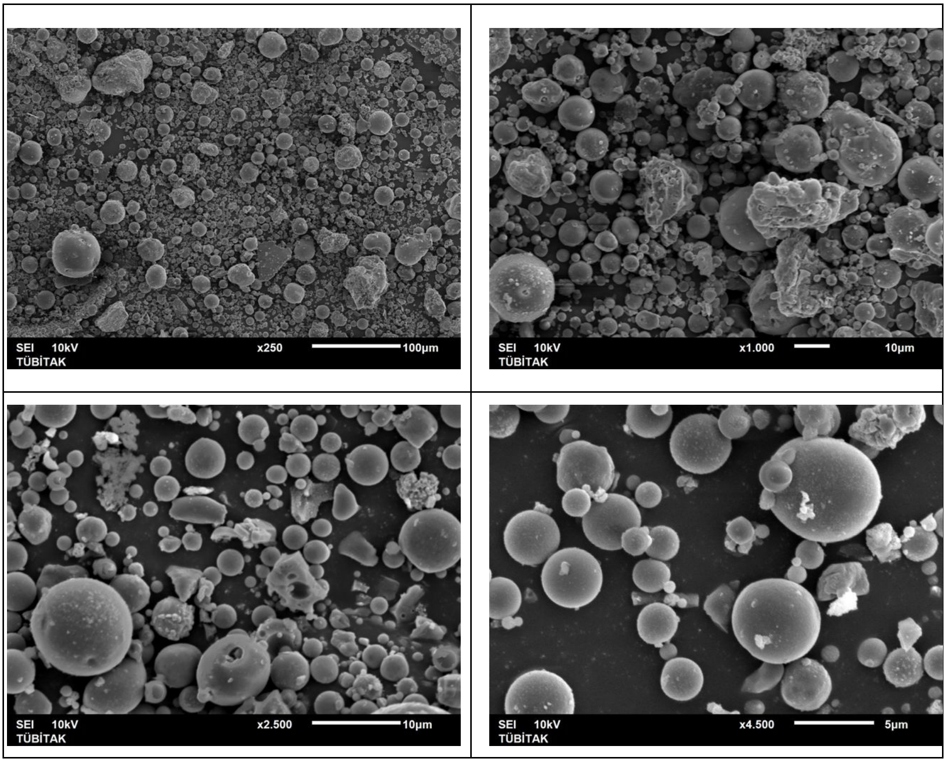


Figure 3. Scanning electron micrographs of fly ash obtained from Orhaneli

The fly ash was characterized for their specific density, average particle size, surface area and pore volume content.

Table 3. The physical properties of the Orhaneli and Kemerköy fly ash

Fly Ash (%)	**Specific Density (g/cm^3)**	**Average Particle Size (µm)**	**Surface Area (m^2/g)**	**Pore volume (cm^3/g)**
Fly Ash From Orhaneli	1.69	142.725	6.709	0.005
Fly Ash From Kemerköy	2.63	57.638	0.694	0.001

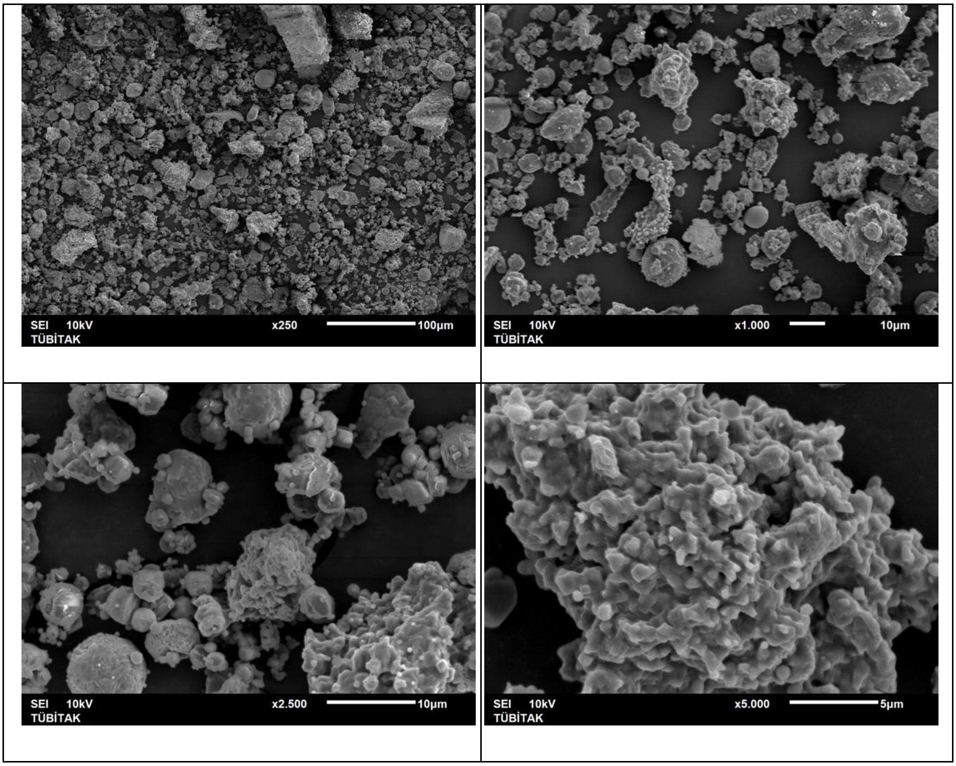


Figure 4. Scanning electron micrographs of fly ash obtained from Kemerköy

3.2. Frictional and Wear Properties

The frictional behavior of our composite as determined by constant speed friction tester (JIS D 4411 friction test standart) measurements is summarized in Table 4. We have also reproduced the observed frictional behavior of a commercial railway brake linings for comparison in Table 4. The effect of fly ash particles into our composites had a profound effect on the frictional behavior as can be seen from Figure 5 and Figure 6.

The commercial railway brake contained lubricants to reduce wear, while our composites did not contain any lubricants for wear reduction. Fly ash filler considerably enhanced the average frictional coefficient of the composites, due to chemical components of fly ash including abrasive particles like SiO_2, Al_2O_3, Fe_2O_3. The friction coefficient and wear characteristics of the friction material depend on the nature of the friction layer.

Table 4. Frictional results of developed brake linings (F9 and F10) and commercial brake linings

Sample Code	**F9 (Orhaneli)**	**F10 (Kemerköy)**	**Commercial Sample Railway Disk Lining 1**	**Commercial Sample Railway Disk Lining 2**
Friction Coefficient Range				
100 °C	0.421-0.436	0.389-0.406	0.381-0.404	0.423-0.457
150 °C	0.357-0.368	0.385-0.432	0.366-0.341	0.484-0.506
200 °C	0.270-0.265	0.425-0.467	0.335-0.294	0.489-0.494
250 °C	0.197-0.177	0.452-0.468	0.289-0.284	0.435-0.412
300 °C	0.170-0.177	0.364-0.361	0.269-0.265	0.378-0.344
350 °C	0.146-0.145	0.299-0.259	0.262-0.249	0.348-0.33
Wear Rate $(cm^3/Nm*10^{-7})$				
100 °C	0.159	0.061	0.204	0.118
150 °C	0.473	0.056	0.278	0.210
200 °C	0.641	0.025	0.756	0.296
250 °C	0.976	0.072	1.244	0.872
300 °C	1.807	0.398	1.998	1.478
350 °C	2.010	0.637	1.157	1.967

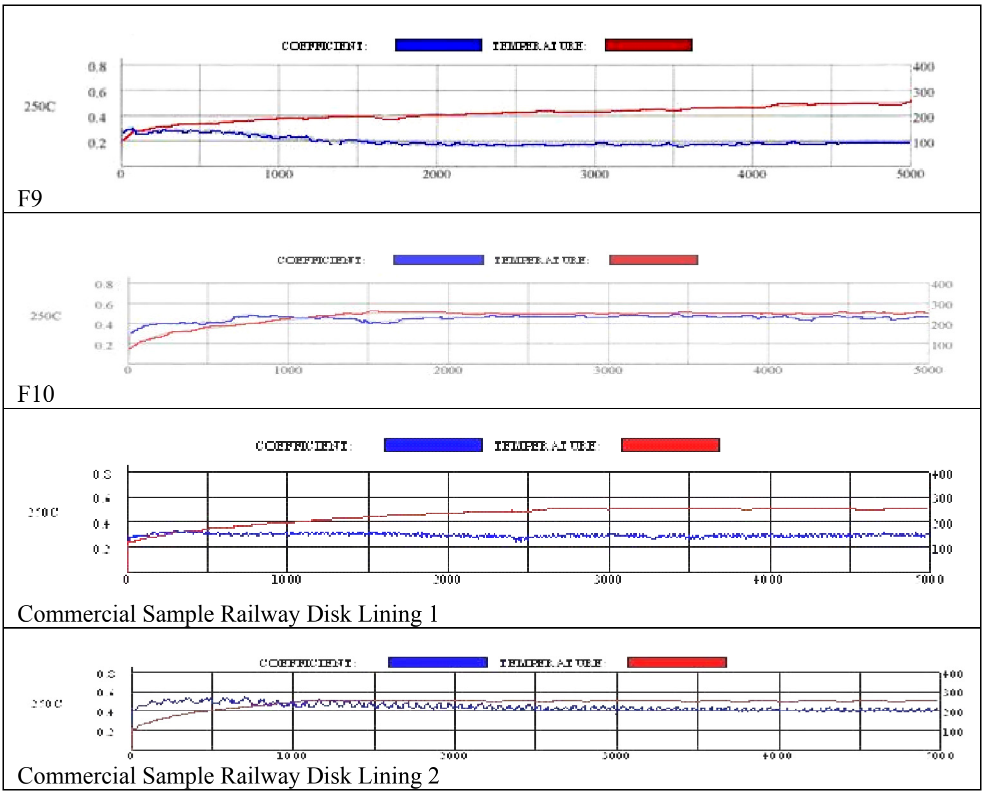


Figure 5. Frictional results of developed brake linings and commercial brake linings at 250 °C

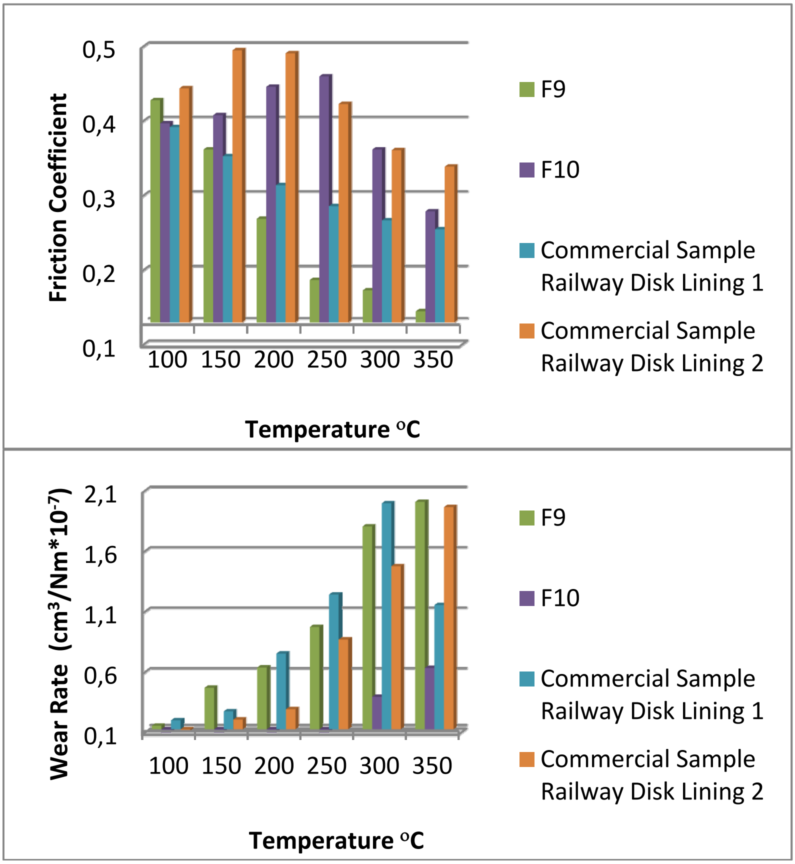


Figure 6. Frictional results of developed brake linings and commercial brake linings

The addition of fly ash into a composite formulated influenced the mechanical behaviors of the composites. The results of mechanical behavior of developed brake linings and commercial brake linings are presented in Table 5. Acetone extraction of the cured powdered mix has also been carried out to estimate the amount of uncured resin or any other organic fraction to define the composites more accurately. The mechanical properties such as hardness, compressibility and shear strength broadly are dependent on the composition range.

Table 5. Mechanical behavior of developed brake linings and commercial brake linings

Sample Code	Hardness (HRL)	Density (g/cm^3)	Internal Shear Strength (MPa)				Compressive Modulus of Elasticity (MPa)	Loss on Ignition (%)
			Normal	Water	Salty Water	In Oil		
Orhaneli (F9)	107	1.79	15	3	10	16	376	33
Kemerköy (F10)	112	2.18	46	0.43	19	14	448	33
Commercial Sample 1	111	2.08	22	13.66	34.77	23.81	316	25.84
Commercial Sample 2	87	2.30	23	26.71	25.48	22.76	321	26.26

4. CONCLUSIONS

This paper concentrates on the friction and wear characteristics of a fly ash based railway disk brake linings. Railway brake materials are complex composites consisting of a combination of numerous ingredients (typically 15–30) necessary for the optimization of their friction and wear performance. The frictional performance strongly depends on the friction layer generated on the friction surface, chemistry, and structure of the friction layer different from the bulk material formulation and also depends on the environment and applied testing condition. Analysis of the experimental results indicate that the brake lining material containing fly ash significantly improved the stability of the friction coefficient and wear resistance.

The influence of fly ash on mechanical, frictional, thermal and wear behaviors of brake friction materials was investigated. The conclusions were summarized as follows:

Fly ash can replace the other filler materials because it exhibits similar properties with those materials. Fly ash is a very good alternative to brake lining filler and can replace filler in many processes in order to minimize the cost. The wear resistance of commercial railway disc brake linings is higher than the fly ash based disc brake linings , which were produced in the laboratory conditions. Compressive modulus of elasticity of fly ash based composite is higher than commercial dics brake linings for railway. The developed composite brake linings can be 10-20% lighter than commercial railway brake linings. Fly ash based composites which are F9 and F10, exhibited lower and more stable friction coefficients.The present study has successfully demonstrated that there is a high potential for commercial applications of brake linings products including fly ash as a filler. Thus employement of fly ash as a filler or reinforcement for brake linings is very suitable from environmental and cost reduction stand points.

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Short Biography

Eyüp Akagündüz was born 1982. He graduated from Kocaeli University Department of Metallurgy and Materials Engineering in 2005 and finished hisMSc (master of science) degree studies at Gebze Institute of Technology. He started working at THE SCIENTIFIC AND TECHNOLOGICAL RESEARCH COUNCIL OF TURKEY (TUBITAK) MARMARA RESEARCH CENTER (MAM) Materials Institute as a scholarship researcher in 2006 and has been a fellow researcher since 2007. He currently pursues his PhD degree at thesis phase at Yildiz Technical University Department of Metallurgy and Materials Engineering on the subject of friction materials and composite materials.