Wear behavior of brake rotor made of AlSi-SiC composites

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ABSTRACT

AlSi alloy based composite brake rotors were made of AlSi alloys (Al-9%Si, Al-12%Si) reinforced with two volume percentages (10 and 20%) of SiC particles using simple and low-cost stir casting technique. Dry sliding frictional and wear behavior were investigated in a pin-on-disc type apparatus. Automobile friction material was used as a disc, while the composite rotor was a pin. The wear and friction behavior of brake rotors made of composites and cast iron one sliding against automotive friction material was examined under loads of 35.6 and 23.6 N and speeds of 5 and 7 m/s. The coefficient of friction increased for all composite brake rotors up to a maximum and then gradually declined, reaching a stationary condition with a load of 23.6 N at a speed of 5 m/s. The coefficient of friction of the cast iron brake rotor alternately reduced and increased. The coefficient of friction of all the brake rotors under investigation increased with increasing the sliding distance as the test speed was raised from 5 to 7 m/s. The coefficient of friction of composite brake rotors had a homogeneous plateau in the range of 0.3-0.57. The coefficient of friction of cast iron brake rotors was around 0.2, but it increased and decreased alternatively. The presence of SiC particles and an adherent mechanically mixed layer (MML) with a hardness that is about 4 times higher than that of the AlSi alloy matrix protected the worn surface against disruption and delamination in the case of composite brake rotors. The worn surface of the cast iron brake rotor was delaminated and brooked down. The composite brake rotor made of Al12Si+10%SiC showed the best wear behavior, and it can replace the cast iron one in light of the present findings.

1 INTRODUCTION

Composite materials are a combination of two or more materials that are not dissolved to improve mechanical, physical and tribological properties. Aluminum matrix composites have significant benefits where they have the combination of lightweight and outstanding mechanical and tribological properties [1]. SiC particles are the most commonly used as reinforcements in aluminum matrix composites because addition of SiC particles to aluminum alloys significantly improves wear properties [2]. Al-SiC composites have many applications in automotive industry such as pistons, cylinder liners and brake rotors [1,3]. Aluminum matrix composites can be manufactured by several methods. However, stir casting is an ideal method to fabricated aluminum matrix since it is more affordable, easier to use, and requires fewer working steps. Additionally, by employing conventional foundry techniques, high production rates can be attained. Stir casting can be used to produce large and intricate shapes at an affordable price.

Approximately 33% of all CO_2 emissions and 26% of all greenhouse gas (GHG) emissions in the US are attributed to the transportation sector in 2020 [4]. The most economical way to minimize fuel use and greenhouse gas emissions from the transportation industry is still to reduce weight. According to estimates, a vehicle's fuel economy increases by 7% for every 10% of weight that is removed from its overall weight. Additionally, this indicates that every kilogram of weight reduced by a vehicle results in a 20 kilograms CO_2 reduction [5]. Replacing steel and cast iron components with aluminum composites is one of the main solutions to save weight and improve fuel consumption efficiency [6].

For Hybrid Electric Vehicles (HEV), which combine an internal combustion engine (ICE) system with an electric propulsion system, lighter materials can be used in place of steel and cast iron. The use of an electric power train aims to improve performance or fuel efficiency compared to a traditional vehicle[7, 8]. Hybrid electric vehicles are most frequently found in the form of cars, Lorries, buses, boats, and aircraft. Several studies were carried out to produce and investigate the properties of brake rotors made of Al based composites. Some of studies used finite element programs to expect properties [9-11]. Other researchers try to produce Al composite brake rotor using sand casting [12] or die casting [11]. Ahmed et al. [13] and Daoud et al. [14] used pin on disc tribometers to compare the wear rate and coefficient of friction of Al matrix composites with cast iron brake disc. Daoud et al [14] produced sand casting Al composite brake rotor from A359-20% SiC using stir casting technique. The investigators have found that the load applied and sliding speed are the key variables that determine the tribological behavior of brake rotors. Additionally, wear resistance is improved by the homogenous particle distribution throughout the matrix material and the strong interfacial bonding between the matrix and reinforcement. Si phase and SiC particles carry the most of wear load and increased adhesion and abrasion resistance [15].

According to our knowledge, no prior work has been done involving the fabrication of SiC-reinforced automobile brake rotors from AlSi alloys utilizing the stir casting method and a permanent mould. In order to develop permanent mould brake rotors made of AlSi-SiC composites using a low-cost stir casting technology, the current study was done. Cast iron and MMC brake rotor material's tribological behavior was examined in relation to the effects of various loads and speeds. Cast iron and composite materials' wear resistance and frictional characteristics were compared. In order to identify the wear mechanisms, it was also essential to examine the worn surfaces of the friction and composite materials as well as the wear debris.

2 EXPERIMENTAL PROCEDURES

Composite brake rotors made of Al-9Si+10%SiC, Al-9Si+20%SiC, Al-12Si+10%SiC and Al-12Si+20%SiC were produced using stir casting method by adding SiC particles with size of 36-48 μm into molten Al-Si alloys. After achieving a homogeneous slurry, the molten composite was poured into metallic permanent mold having the configuration of commercial automobile brake rotor. Samples from the produced composite brake rotors were cut for metallographic investigation. Microstructure features of the samples were investigated using optical and field emission microscopes. EDX analyses on the interface between matrix and reinforcements were conducted. The produced brake rotors and commercial cast iron one were tested against automotive friction material using pin on disc type apparatus. Samples from produced composite brake rotors made of Al-9Si and Al-12Si reinforced with 10 and 20% SiC particles and commercial cast iron brake rotor were formed as pins and the automotive brake pad was the disc. Two loads of 35.6 and 23.6 N were applied directly on the top of the pin. The wear test was conducted using two linear speeds 5, 7 m/s for 30 min. Weight loss was measured by weighting the sample before and after the test Volume loss of each specimen was measured by dividing weight loss over the density of each specimen. The average coefficient of friction of the produced brake rotor made of composites and commercial cast iron one was calculated from the friction force measured during wear test. Temperatures near the contact surface during the all wears test were measured. Worn surfaces of samples from selective produced brake rotor (Al12Si-10%SiC) and commercial cast iron brake rotor that were tested using applied load of 35.6N and speed of 7m/s were investigated using SEM and EDX. The morphology of the longitudinal section near to the worn surface of the pins for produced composite brake rotors and commercial cast iron one at speed of 7 m/s and applied load of 36.5N was investigated using optical microscope. Hardness along subsurface of composite break rotor from the MML to the matrix was measured using microhardness testing machine.

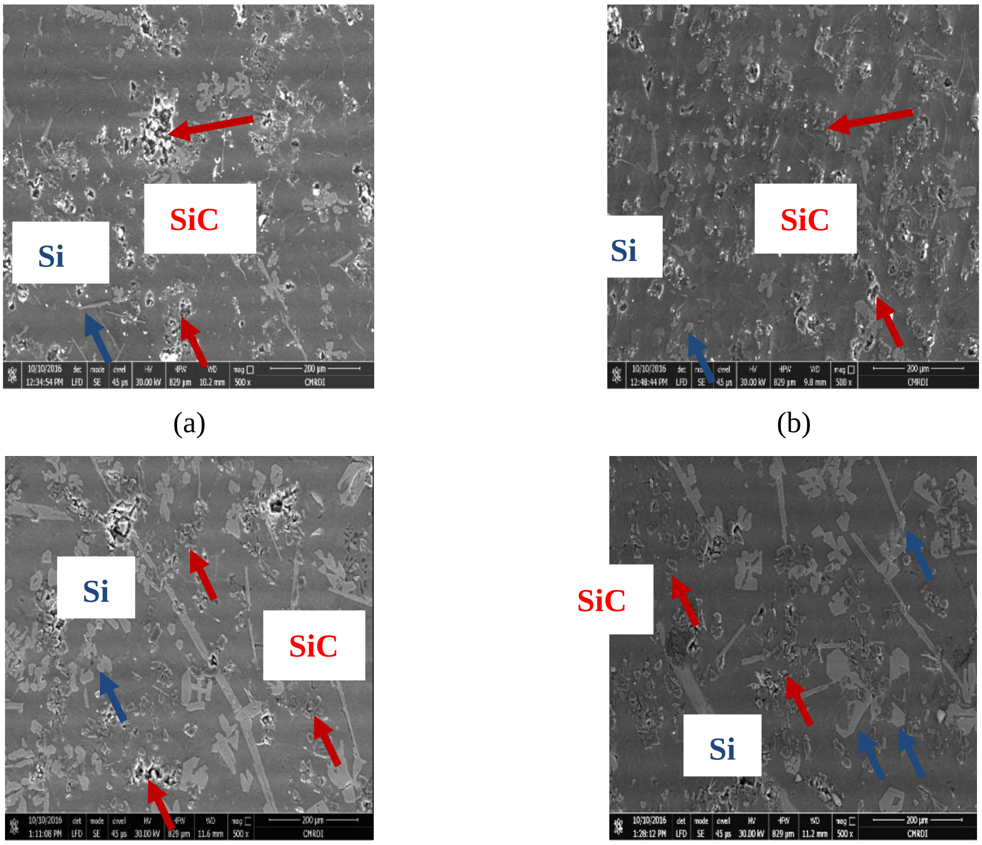
3 RESULTS AND DISCUSSION

3.1 Microstructure

Microstructures of the produced composite brake rotors are shown in Fig.1(a-d). The microstructures reveal relatively good distribution of SiC particles (denoted with red arrows). The distribution of SiC particles is improved by using metallic moulds. The addition of SiC particles results in a refining effect in the Al-Si matrix alloy. Because of the lower heat conductivity and higher specific heat of SiC particles than those of molten Al-Si matrix alloy, dendrites nucleate and grow away from the SiC particles, and the constraint provided by the SiC particles resulted in a finer grain structure. Grain refinement can be seen, particularly near the SiC particles. Figure 1 (a-d) demonstrates the existence of eutectic phase (denoted with blue arrows) around SiC particles. In other words, the SiC particle existence in the composites is primarily between dendritic arms, implying that particles are pushed by primary dendrites and accumulated at eutectic zones. The remaining eutectic melt is rich in SiC particles because SiC particles are pushed into the liquid by the growing primary α phase [16]. Because the eutectic Si could also nucleate on SiC particles in the Al-Si alloy, Fig. 1 (a-d) depicts certain SiC particles that are connected by silicon phases, which is consistent with Wu et al. [17].

3.2 Weight and volume loss

Figures 2-5 show the volume loss of brake rotors made of Al-Si composites and cast iron using loads of 23.06 and 35.6 N and linear speeds of 5 and 7 m/s for 30 min. Cast iron brake rotor has the greatest volume loss for all loads and speeds. Also, the large difference in volume loss between cast iron brake rotor and brake rotors made of Al-Si composites can be observed. Al-12Si+10SiC has lowest volume loss, especially at increasing load from 23.06 to 35.6N and speed from 5 to 7 m/s.



(a) (b) (c) (d)

Fig.1 (a-d) FEM microstructure of the composite brake rotors after heat treatment, (a) Al-9Si+10SiC, (b) Al-9Si+20SiC, (c)Al-12Si+10SiC, (d) Al-12Si+20SiC

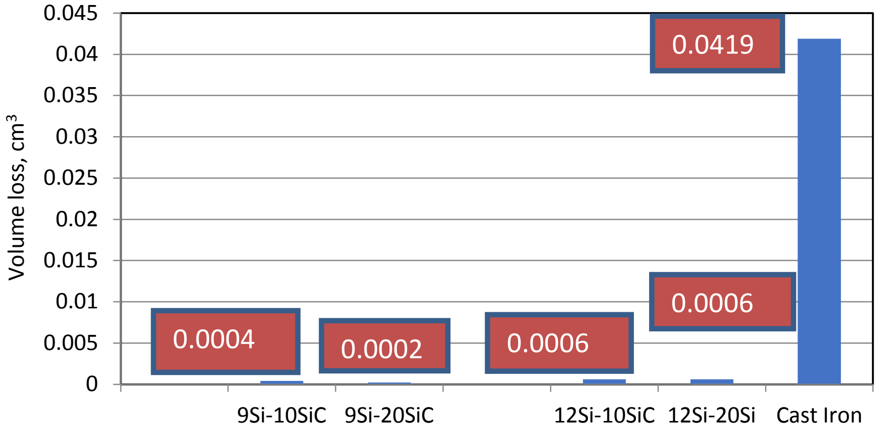


Fig. 2 Volume loss of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 5 m/s and load of 23.06 N

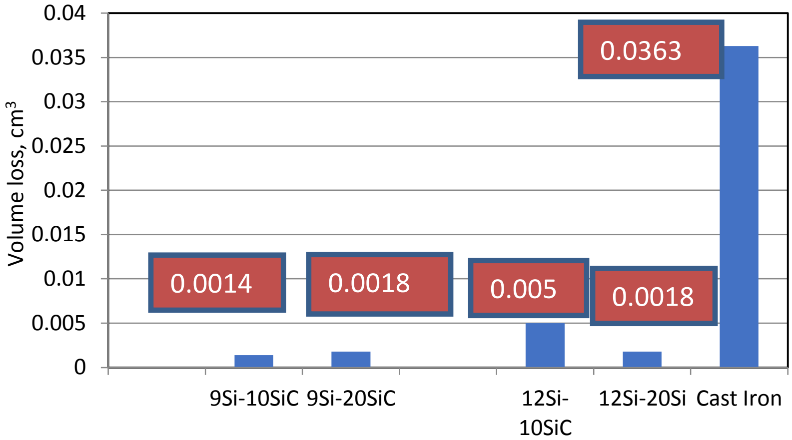


Fig. 3 Volume loss of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 7 m/s and load of 23.06 N

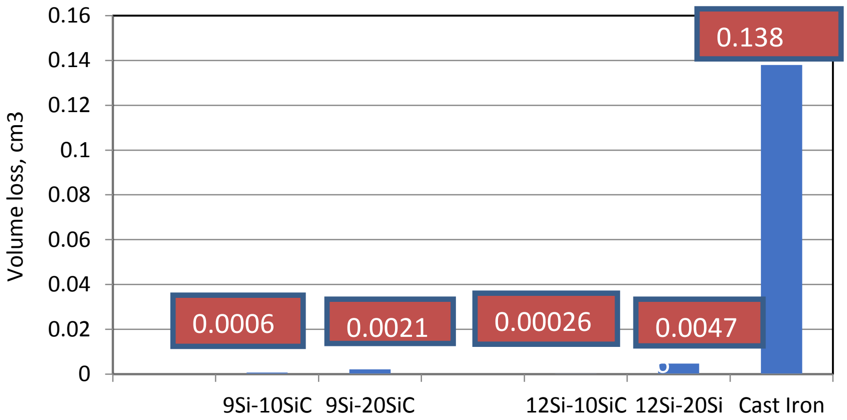


Fig. 4 Volume loss of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 5 m/s and load of 35.6 N

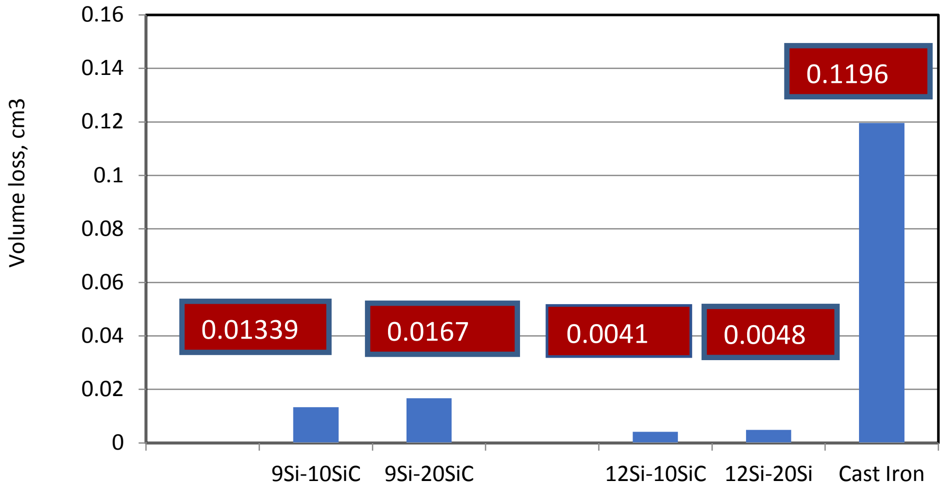


Fig. 5 Volume loss of Al-Si composite Brake rotors and commercial cast iron brake rotor at speed of 7m/s and load of 35.6 N

3.3 Coefficients of friction

The average coefficients of friction of the brake rotors made of AlSi composites and commercial cast iron one were calculated from the friction forces measured during wear test. Fig. 6 shows the average coefficients of friction of brake rotors made of AlSi composites and cast iron brake rotor with sliding distance under applied load of 23.06 N and speed of 5m/s. For composite rotors, coefficients of friction increase during the first 2000 m, except of Al9Si-20SiC, which decreases slightly then increases. All the coefficients of friction of the composites increase up to a maximum and then smoothly decrease, reaching a stationary situation. Because of the frictional heat, the oxide layer can be formed on the surface of the composite rotor pin during the test. Two processes occur concurrently as the wear test continues: the oxide layer breaks down, generating fine oxidized wear debris and at the same time, the assisted by frictional heating oxide layer increases. Eventually, both of these competing processes reach equilibrium [18, 19]. In case of cast iron, coefficient of friction decreases and increases alternatively, revealing irregularity. This may be attributed to the formation and breaking down of the oxide layer on the worn surface. On the pin and disc surfaces, oxide particles and small fragments of silicon and other elements from the friction material (pad disc) are accumulated progressively. The progressive contamination of the wear track modifies the nature of the contact surface. The transfer layer formed on the wear track covers the lubricating agents of the disc, increasing the coefficient of friction with sliding distance [20]. When the speed increases from 5 to 7m/s, the coefficients of friction of brake rotors made from AlSi composites decrease, exhibiting a stationary situation with sliding distance, while coefficient of friction increases rapidly in case of cast iron, Fig.7. As the speed increases, brake rotors made of AlSi composites exhibits lower volume loss, especially in case of Al12Si-10SiC, while cast iron brake rotor shows higher volume loss, Figs. 4 and 5. This can be attributed to delamination of buildup of transfer layer [1].

The effect of increasing load from 23.06 to 35.6 N is shown in Figs. 8 and 9. For brake rotors made of AlSi composites, the coefficient of friction decreases with increasing the load, but all of them in the range of 0.3-0.57. The decrease in coefficient of friction can be attributed to the formation of strongly compacted transfer layer, which protects the composite disc from adhesion and abrasion. In case of cast iron brake rotor, the coefficient of friction decreases drastically by increasing the load to around 0.2, without exhibiting a stationary situation as in case of composites, but it decreases and increases alternatively.

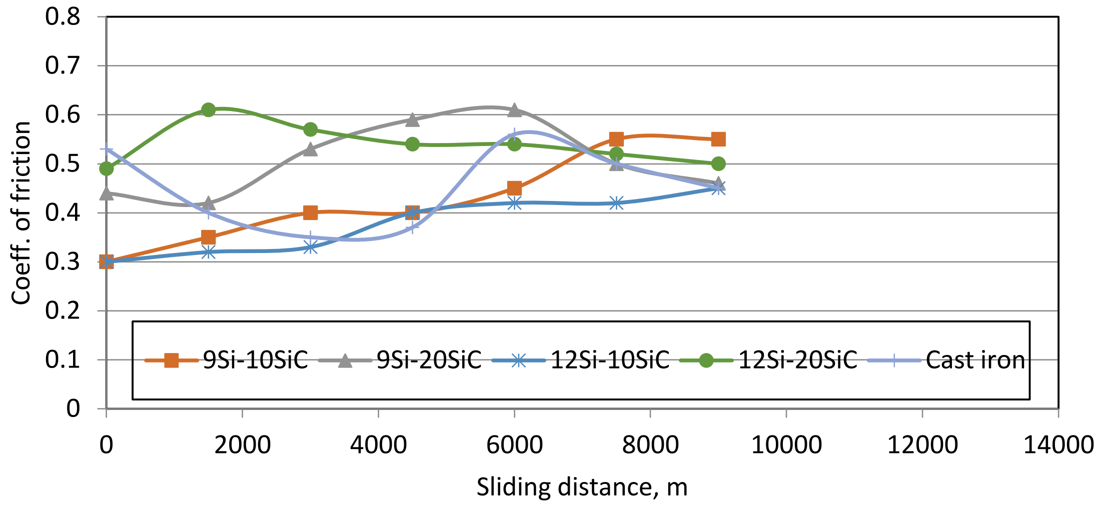


Fig. 6 Coefficient of friction of composite brake rotors produced and commercial cast iron brake rotor at load of 23.06 N and speed of 5m/s

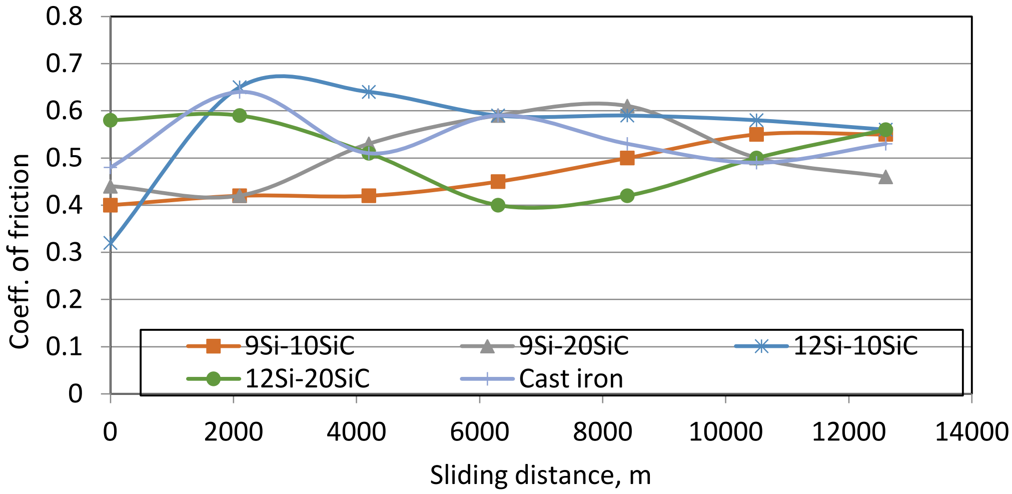


Fig. 7 Coefficient of friction of composite brake rotors produced and commercial cast iron brake rotor at load of 23.06 N and speed of 7m/s

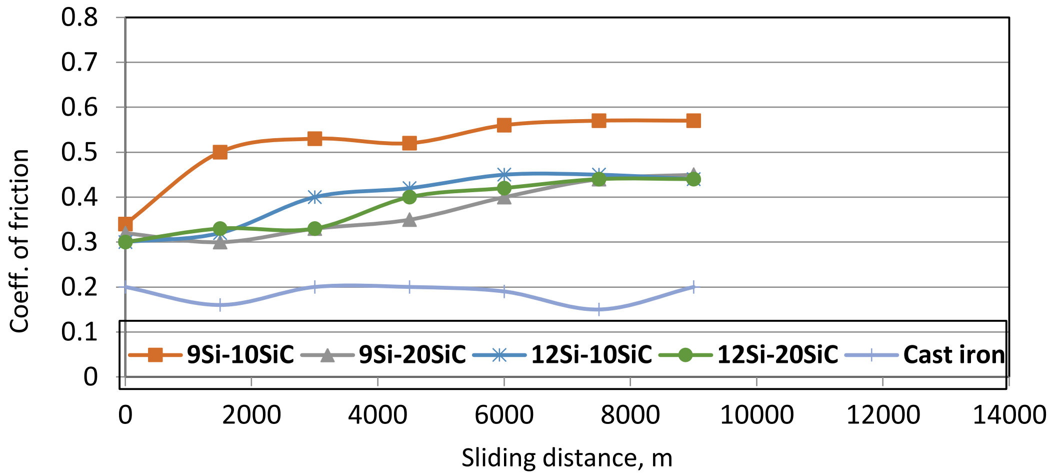


Fig. 8 Coefficient of friction of composite brake rotors produced and commercial cast iron brake rotor at speed of 5m/s and load of 35.6 N

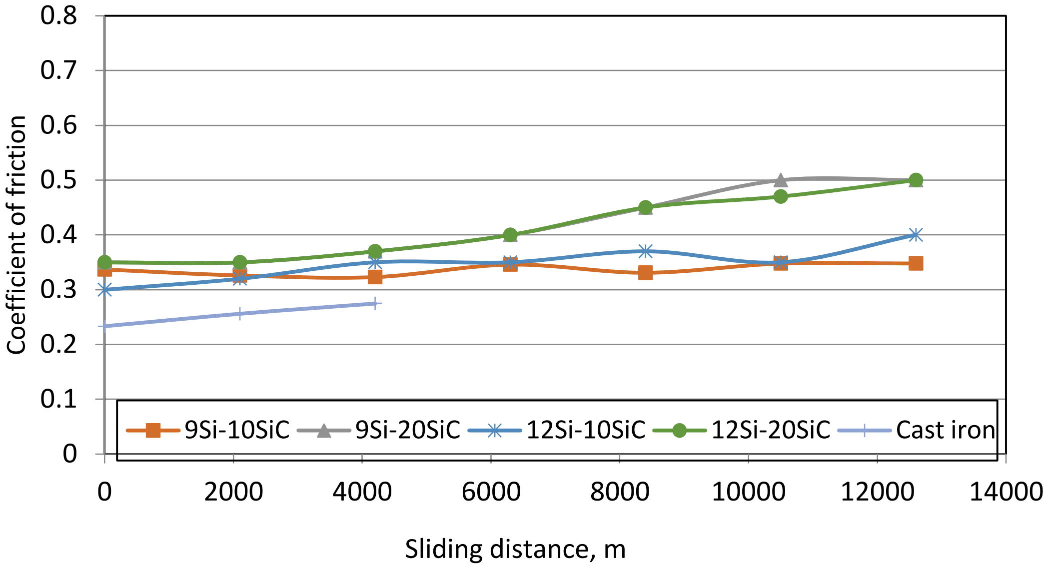


Fig. 9 Coefficient of friction of composite brake rotors produced and commercial cast iron brake rotor at speed of 7m/s and load of 35.6 N

Temperatures near the contact surface during all he were test were measured for all brake rotors, Figs. 10-13 show the temperature behavior of produced brake rotors made of AlSi composites and cast iron brake rotor. For the brake rotors made of AlSi composites, temperature increases at the first 5000 m, then it exhibits a plateau, Figs 10, 11, 12. Increasing load from 23.06 to 35.6 N has a marginal effect on the temperature behavior of the brake rotors along sliding distance. Also, increasing speed from 5 to 7 m/s doesn't have a tangible effect on the temperature behavior of composites, Figs. 12, 13. On the other hand, temperature of cast iron increases along sliding distance, Fig.10. Increasing speed from 5 to 7 m/s increases the temperature of cast iron up to 250˚ C, Fig.11. While increasing speed from 5 to 7 m/s causes a dramatic temperature increase, increasing load from 23.06 to 35.6 N has no effect on temperature, Fig.13. As a result of friction, the contact temperature increases, leading to formation of adhered oxide layer mixed with some particles and lubricating agent of the friction material disc. This mixed layer protect contact surface of composite brake rotor from delamination [19, 22, 23]. However, in case of cast iron brake rotor, the oxide layer that formed on the contact surface is not adhered as that in case of Al composite brake rotor. Therefore, it brooked down during the test and delamination is occurred [24].

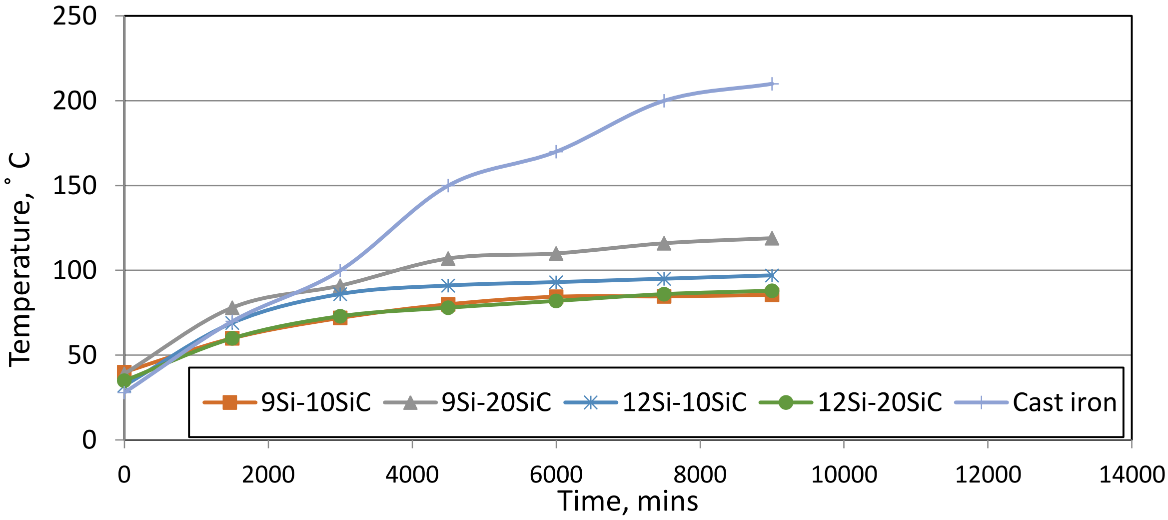


Fig. 10 Temperature behavior of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 5 m/s and load of 23.06 N

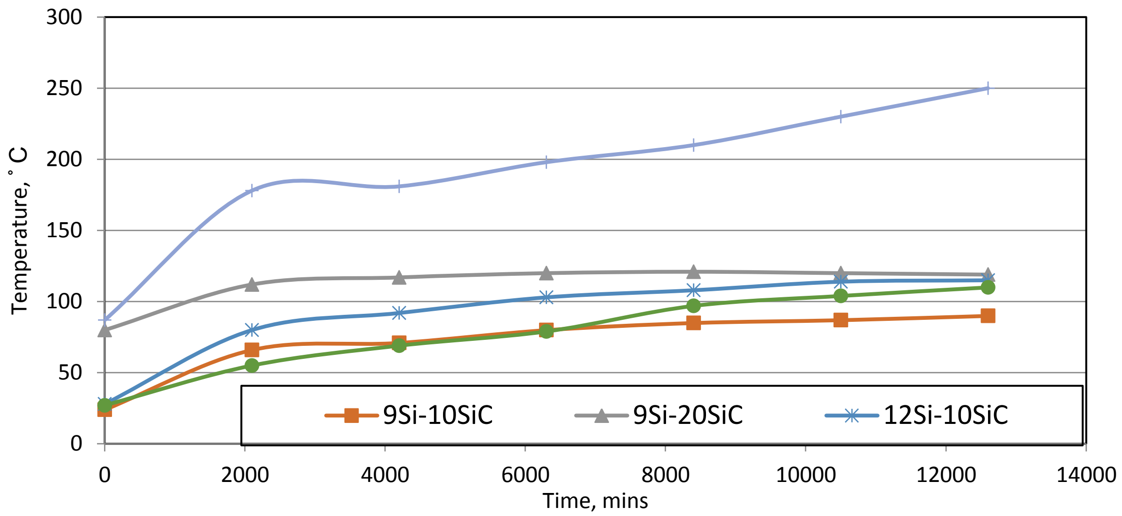


Fig. 11 Temperature behavior of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 7 m/s and load of 23.06 N

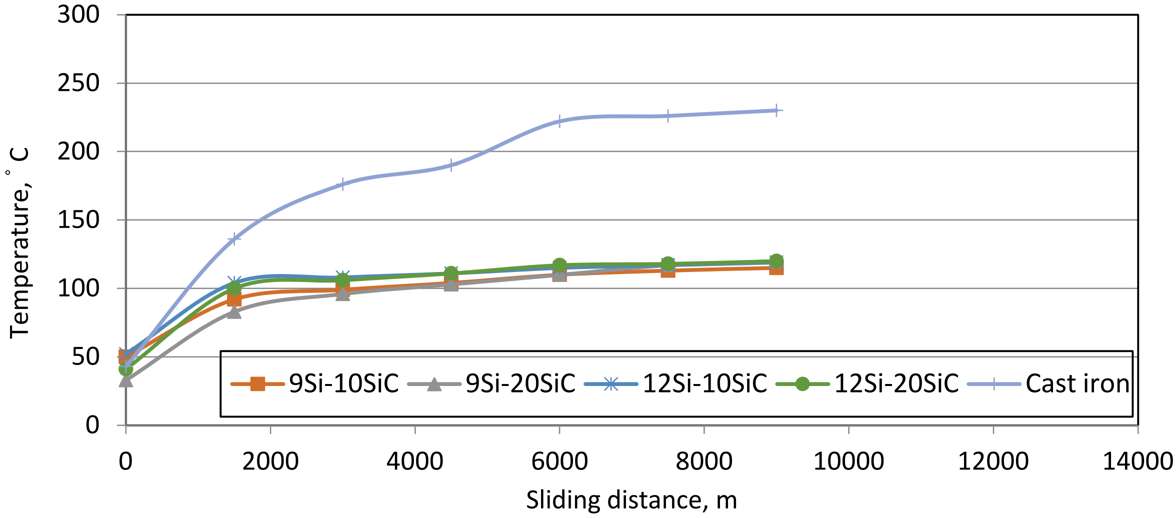


Fig. 12 Temperature behavior of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 5 m/s and load of 35.6 N

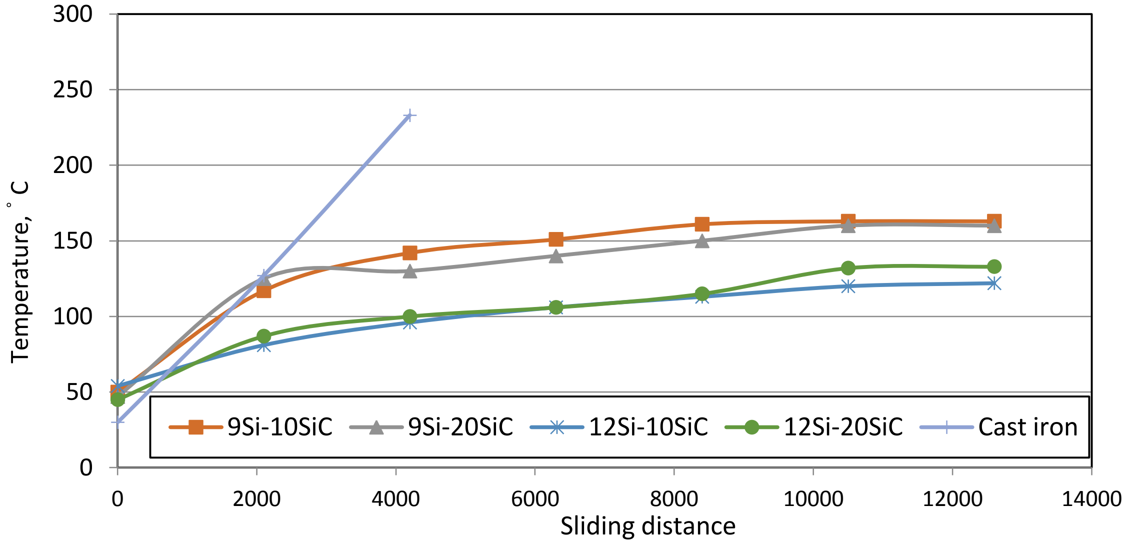
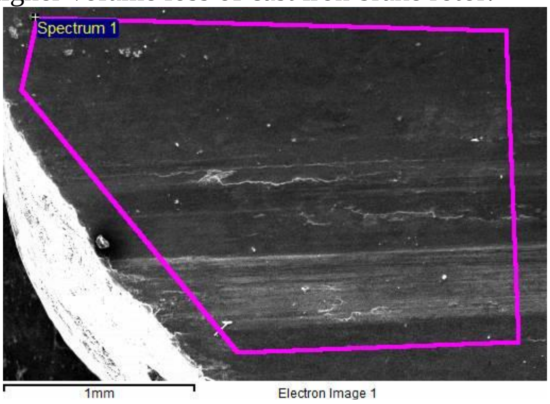


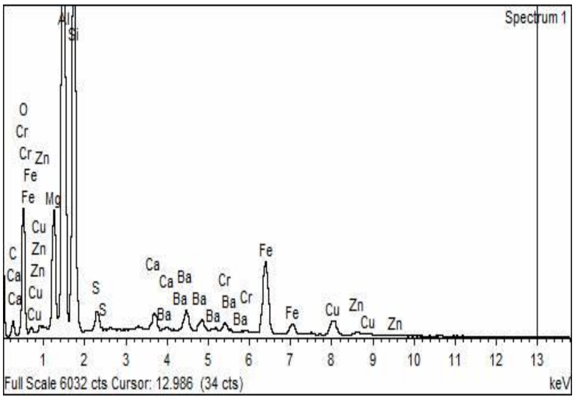
Fig. 13 Temperature behavior of Al-Si composite brake rotors and commercial cast iron brake rotor at speed of 7 m/s and load of 35.6 N

3.4 Worn surface

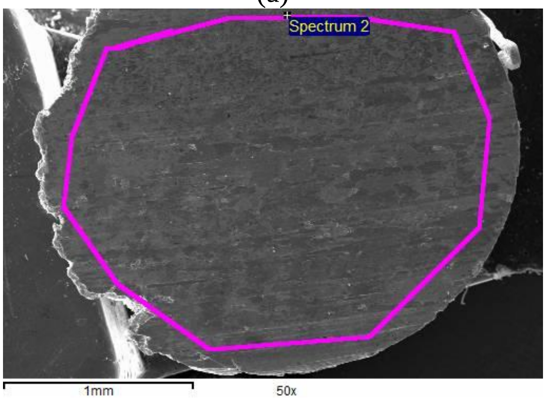
Figure 14(a-f) shows SEM and EDX analysis of worn surfaces of samples from selective produced brake rotor (Al12Si-10%SiC) and commercial cast iron brake rotor tested using applied load of 35.6N and speed of 7m/s. Fig.14a shows the worn surface of Al12Si+10SiC at a low magnification. Bright track that refers to presence of fine oxide particles adhered on the contact surface can be seen. Dark smooth tracks, which are delaminated debris from the friction materials and adhered to the composite pin surface, can also be observed. The EDX analysis of the worn surface is illustrated in Fig.14b, which indicates presence of oxygen, aluminum, carbon, barium and other elements that form friction material. The EDX analysis indicates the formation of the mechanically mixed layer that protects worn surface from disruption and delamination. Presence of aluminum oxide and carbon on the surface leads to the formation of a strong adhered layer. At the same time, existence of carbon on the surface, which acts as lubricating agent, significantly enhances the wear resistance of the Al composite brake rotor, comparing with that of cast iron one. Fracture segments and delamination of the worn surface of cast iron was clearly seen in Fig.14c. Figure 14d shows the EDX analysis of worn surface of commercial cast iron brake rotor. Because of the presence of iron, oxygen, and other elements that fail to adhere to the surface, cracking and delamination occur. Worn surface of the produced Al12Si+10SiC brake rotor at high magnification is shown in Fig.14e. The bright area indicates crushed fine particles of the mechanically mixed layer that mainly formed from Al_2O_3 and some crushed SiC particles (marked with blue arrows). A long crack at the middle of the photo is marked with red arrows. SiC particles impeded in the layer (marked with yellow arrows) can withstand and carry the load, protecting the worn surface from delamination. Dark areas (marked with white arrows) indicate areas covered with the graphite protected layer. Worn surface of commercial cast iron brake rotor is shown in Fig.14f. Many cracks are found on the worn surface (marked with red arrows). Delamination of the worn surface is clearly seen (marked with white arrows), which explains higher volume loss of cast iron brake rotor.



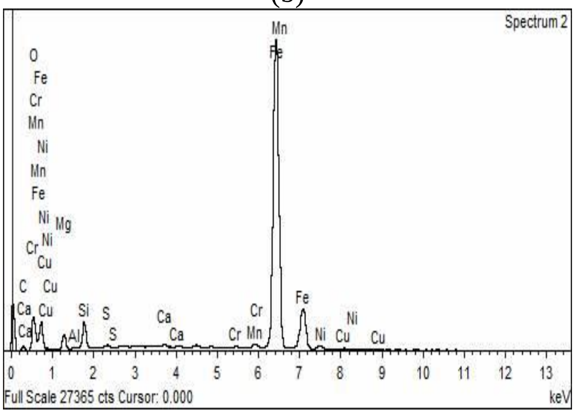
(a)



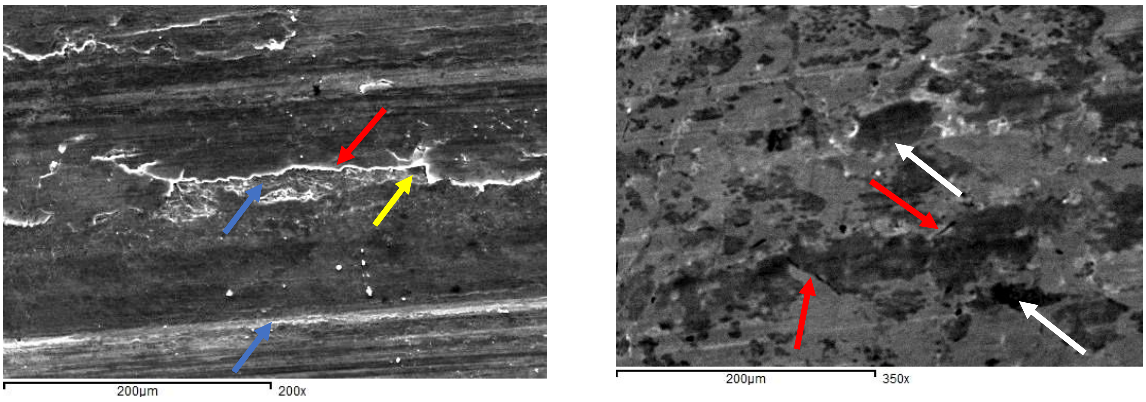
(b)



(c)



(d)



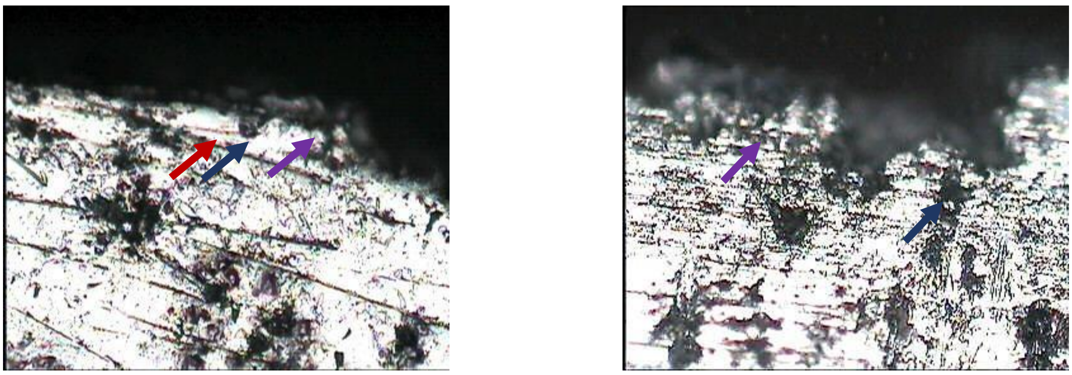
(e) (f)

Fig. 14 Worn surface of brake rotor made of Al12Si + 10%SiC compared and commercial one made of cast iron at load of 35.6 N and speed of 7m/s, a) low magnification of worn surface of Al12Si+10%SiC, b) EDX for Al12Si+10%SiC, c) low magnification of worn surface of cast iron, d) EDX of cast iron worn surface, e) higher magnification of worn surface of Al12Si+10%SiC, f) higher magnification of worn surface of cast iron

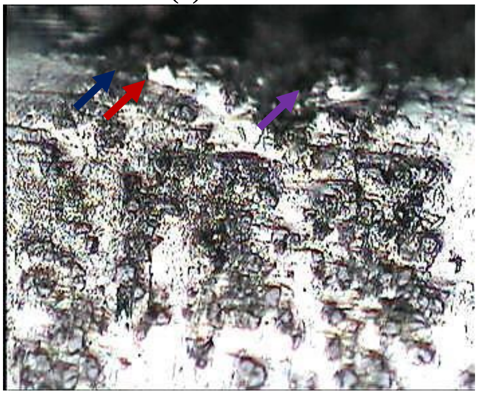
3.5 Subsurface of the worn surface

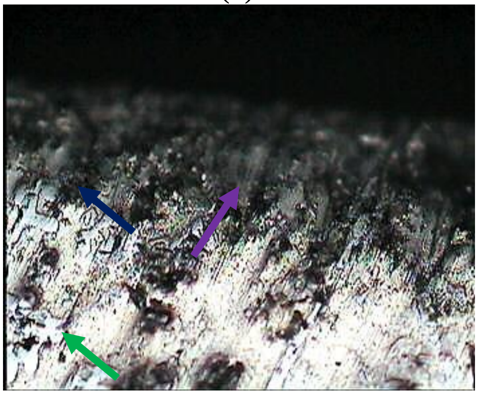
The morphologies of the longitudinal section near to the pin worn surfaces of the composite brake rotors and commercial cast iron one at speed of 7 m/s and applied load of 36.5N are shown in Fig.15(a- e). Fig. 15 (a-d) reveals some cracks (pointed by the red arrows) under the worn surface, and parallel to it. Also, crushed SiC particles (pointed by violet arrows) that are protected the surface against delamination can be noted. Initially, the asperities of the sliding pin surface encounter the brake pad that was fixed on the rotating disc. The surface work hardening of the matrix material takes place under the applied load and speed [25]. The projected SiC particles, which have high strength, are pushed back into the soft AlSi alloy instead of fracturing. During the initial run-in period in all cases, the wear rate is high because of the fact that few broken SiC particles from the pin, acting as third body abrasion, leaving the projection of SiC in the composite [26]. In other words, the wear rate at the beginning is more because of the fact that the asperities of SiC particles were not projected and the entire surface is under the same amount of stress such that the asperities will be deformed easily and the fractured matrix material particles and SiC particles will plough the surface of the counter- face and the pin.

When the speed increases, the ploughed surface of the brake pad counter face forms a mixture of brake pad powder and SiC particles that are crushed and formed very minute particles [26 -28]. The brake pad powder and minute fractured particles of the SiC form a layer between the work- hardened pin and the counter face, reducing the wear rate and coefficient of friction. On the other hand, worn surface of cast iron exhibits cracks that are pointed by blue arrow, causing delamination. Delamination causes deep groves that are pointed by green arrow. These delaminated species were separated from the surface and pointed by red arrow, Fig.15 (e). Fig. 16 (a, b) shows SEM and EDX analysis of worn surface of pin from selective produced brake rotor (Al12Si+10%SiC) tested using applied load of 35.6N and speed of 7m/s.



(a) (b)





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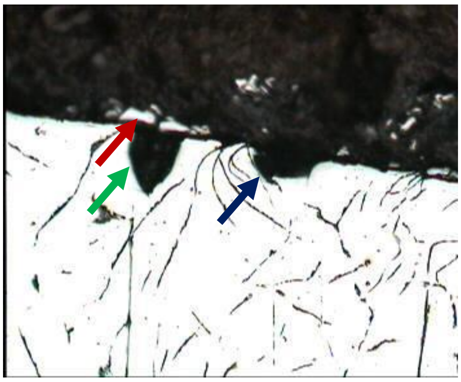
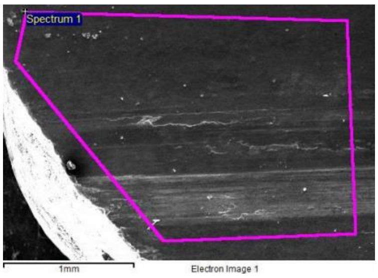
(c) (d)

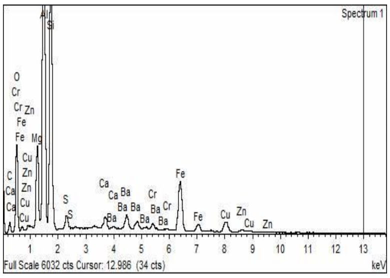


(e)

Fig.15 Subsurface of worn surface of produced composite brake rotors and commercial cast iron one, (a) 9Si-10SiC, (b) 9Si-20SiC, (c) 12Si-10SiC, (d) 12Si-20SiC, (e) cast iron

Fig. 16 (a) shows the worn surface of Al12Si+10SiC at low magnification. Bright track refers to presence of fine oxide particles adhered on the contact surface and dark smooth tracks can be observed. These dark smooth areas are referred to presence of particles from the friction materials (brake pad) that are delaminated from the brake pad material surface and adhered to the composite pin surface. The EDX analysis of the worn surface is illustrated in Fig.16 (b), which indicates presence of oxygen, aluminum, carbon, barium and other elements that form friction material. It indicates formation of the mechanically mixed layer that protects the worn surface from disruption and delamination. Presence of aluminum oxide and carbon on the surface leads to formation of strong adhered layer. At the same time, presence of carbon on the surface, which acts as lubricating agent, acts a main role in reducing volume loss of the Al composite brake rotor comparing with cast iron one. The protecting layer formed on the surface of composite brake rotor contains graphite that smears and forms a protecting layer. As mentioned above, the powdered SiC particles along with ferrous oxides from the counterface, aluminum oxides and SiC from the pin as well as graphite and aluminum oxide from aluminum matrix and the brake pad disc are mixed, forming mechanically mixed layer (MML). The hardness of the MML is much higher than that of the pin and the counterface.





(a) (b)

Fig.4.2 Worn surface of brake rotor made of Al12Si + 10%SiC at load of 35.6 N and speed of 7m/s , a) low magnification of worn surface of Al12Si+10%SiC, b) EDX for Al12Si+10%SiC

As seen in Fig. 17, hardness is higher at the MML and close to the worn surface at 10 µm (266 HV), than at 30 µm (175 HV), and it declines to 119 at 70 µm in the matrix. Referring to Fig.16 (b), the presence of oxygen, iron and graphite is observed and indicates the formation of Al_2O_3, Fe_3O_4, which are the main oxides that form the MML in addition to graphite that play a very crucial role in that layer to protect the pin surface.

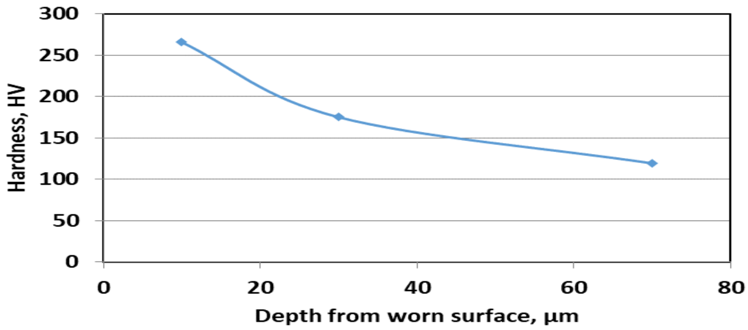


Fig.4.3 Microhardness of mechanically mixed layer

4 CONCLUSIONS

1. AlSi –SiC composite brake rotors were successfully produced utilizing stir casting method and a permanent mould.
2. Microstructure of AlSi composite brake rotors reveals uniform distribution of SiC particles and eutectic phase around them.
3. Composite brake rotors exhibit higher wear resistance than that of cast iron one. Al-12-Si-10SiC has the better wear resistance, especially as the load increases from 23.06 to 35.6 N and speed from 5 to 7 m/s.
4. The coefficient of friction decreases by increasing load for all composites, but all of them in range of (0.3-.057), reaching a stationary situation. In case of cast iron brake rotor, the coefficient of friction decreases drastically to around 0.2 with increasing and decreasing alternatively.
5. The coefficient of friction of composite brake rotor decreases with increasing speed from 5 to 7 m/s, offering a uniform manner along sliding distance, while coefficient of friction increases rapidly in case of cast iron brake.
6. Increasing load from 23.06 to 36.6 N or speed from 5 to 7m/s has no significant effect on temperature behavior the composite rotors. In case of cast iron, increasing load from 23.06 to 36.6 N doesn’t increase temperature, but increasing speed from 5 to 7 m/s increases temperature sharply.
7. In case of composite break rotors, crushed SiC, aluminum oxide and carbon are formed mechanically mixed layer (MML) that protects worn surface from disruption and delamination. Ploughing is the main mechanism of wear of the composite brake rotor at the beginning of the wear test until formation of MML, which has higher hardness with approx. 4 times than AlSi matrix. In case of cast iron, brake rotor, delamination of the worn surface is the main mechanism of volume loss during the wear test.

REFERENCES

[1] Harmeet Singh, Gurinder Singh Brar, Harish Kumar, Vikrant Aggarwal, A review on metal Matrix Composites for Automobile Applications, Materials Today Proceedings, Vol.43, Part1, 2021, 320-325.

[2] F M Firouz, E Mohamed , A Lotfy , A Daoud and M T Abou El-Khair, Thermal expansion and fatigue properties of automotive brake rotor made of AlSi–SiC composites, Mater. Res. Express, Vol. 6, 2019, 1265d2.

[3] S.T.Marhungu, E.T.Akinlabi, M.A.Onitiri, F.M.Varchia, Aluminum Matrix Composites for Industrial Use:Advanced and Trends, Procidia Manufacturing, Vol.7, 2017, 178-182.

[4] http://epa.gov/ghgemissions/overview-green house-gases.

[5] Karan C.Prajapati, Ravi Patel and Rachit Sagar,”Hybrid Vehicle: A Study on Technology”, International Journal of Engineering Research&Technology (IJERT), Vol. 3, 12, Decembre-2014.

[6] https://afdc.energy.gov, “How Do Hybrid Electric Cars Work? “

[7] Caiying Shen, Peng Shan and Tao Gao, “A Comprehensive Overview of Hybrid Electric Vehicles”, International Journal of Vehicular Technology, Vol. 2011.

[8] Sakthivel C, Dr.Jayaprakash M, Abner Leo N, Madheswari J, Anbuchandran S, "Hybrid Electric Vehicle Design", Global Research and DevelopmentJournal for Engineering /National Conference on Engineering Trends in Electrical, Electronics and Computer Engineering (ETEEC-2018), April-2018.

[9] Adebist. A A, Maleque M A and Shah Q H, Surface temperature distribution in a composite brake rotorInternational Journal of Mechanical and Materials Engineering(IJMME), Vol. 6, 2011, 356–361.

[10] Govindan M and Viji B 2017 Design and analysis of automobile brake disc by using Al/SiC MMCInternational Journal of Innovative Research in Science, Engineering and Technology 6.

[11] Sadagopan P, Harish Karthi N and Praveen Kumar J 2018 Study of silicon carbide-reinforced aluminium matrix composite brake rotor for motorcycle application Int. J. Adv. Manuf. Technol. 94 1461–75.

[12] Daoud A and Abou El-Khair M T 2010 Wear and friction behaviour of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material Tribology International 43 544–53.

[13] Ahmad F, Lo S H J, Aslam M and Haziq A 2013 Tribology behaviour of alumina particles reinforced aluminium matrix composites and brake disc materials Procedia Eng. 68 674–80.

[14] P K Dinesh Kumar and S Darius Gnanaraj, Aluminium-Silicon based Metal Matrix Composites for brake rotor applications: a review, Eng. Res. Express 5 (2023) 022002.

[15] Jiang L, Li J Y, Yu L, Liang Y H, Shen L Z, Dong D Y and Feng F G 2019 Fabrication, microstructure, friction and wear properties of SiC3D/Al brake disc−graphite/SiC pad tribo-couple for high-speed train Trans. Nonferrous Met. Soc. China (English Ed.) 29 1889–902.

[16] J.Xu, X.Liu, E.Barbero, J.G.Hemrick, M.Peters,"Wetting and reaction characteristics of Al2O3 /SiC composite refractories by molten aluinium and aluminium alloy", International Journal of Applied Ceramic Technology, Vol.4, 2007, 514-523.

[17] S.Wu, Y.You, P.An, T.Kanno, H.Nakae,"Effect of modification and ceramic particles on solidification behavior of aluminium-matrix composites", Journal of Materials Science, Vol.37, 2002, 1855-1860.

[18] Y.Liu, R.Asthana, P.Rohagi, J.Mater.Sci., 26, 1991, 99.

[19] L.Lasa, J.M.Rodriguez-Ibabe, "Wear behavior of eutectic and hypereutectic Al-Si-Cu-Mg casting alloys tested against a composite brake pad", Materials Science and Engineering A, 363, 2003, 193-202.

[20] G.Straffelini, "A simplified approach to the adhesive theory of friction", Wear, 2001, 249, 79-85.

[21] S.Basavarajappa, G., Chandramohan,"Dry sliding wear behavior of hybrid metal matrix composites", ISSN1392-1320 materials scince (medziactorya), Vol.11, 2005, 253-257.

[22] L.Francis Xavier and Paramasivam Suresh, "Wear behavior of aluminum metal matrix composite prepared from industrial waste", The Scientific World Journal, 2016, Article ID 6538345.

[23] Mihaly Kosma, "Friction and wear of aluminum matrix composites", Research Gate, January 2003.

[24] S. Basavarappa, G.Chandramohan, K.Mukhund, M.Aswin, M.Pra,"Dry sliding wear behavior of Al 2219/SiC/gr hybrid metal matrix composites", Journal of materials engineering & performance, Vol.15, 2006, 669-674.

[25]C.Gonzalez, A.Martin, J.Llorca, M.Garrido, M.Gomez, ARico, J.Rodriguez, "Numerical analysis of pin on disc tests on Al-Li/SiC composites", Journal of Wear, Vol. 259, 2005, 609-612.

[26] S.R.Chauhan, K.Anoop, I.Singh, P.Kumar, "Effect of fly ash content on friction and dry sliding wear behavior of glass fiber reinforced polymer composites – A Taguchi approach", Journal of Minerals and and Materials Characterization and engineering", Vol. 9, 2010, 356-387.

[27] M.Mares,"Some issues on tailoring possibilities for mechanical properties of particulate reinforced metal matrix composites", Journal of Optoelectronics and Advanced Materials, Vol. 3, 2001, 119-124.

[28] B.Venkataraman, G.Sundarajan, "Correlation between the characteristics of the mechanically mixed layer and wear behavior of aluminium.Al-7075 alloy and AlMMCs", Wear, Vol.245, 2000, 22-38.