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Comparative study of disc brake pads sold in Indian market — Impact on safety and environmental aspects

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ABSTRACT

The new generation brake pad offers innumerable benefits like adequate friction, moderate wear and contributes to environmental pollution as well. There is a need to study the safety and environmental aspects of the brake pads sold in India. The present study included testing of three brake pads from well-established producers including — Original Equipment manufacturer (OE), After Market (Export) (AM(E)) and After Market (AM). In the study of analyzing the safety aspect, the brake pads were tested as per SAEJ661a standard. It was observed that AM(E) and AM had developed a low coefficient of friction of 0.36 and 0.27. Further in the study concerning the wear aspects, the highest wear was observed from sample AM (68.3 g), followed by AM(E) (56.9g) and OE (54.3g). Chemical compositions were also investigated for studying the toxicological aspects. Trace of asbestos, a banned fiber was detected in one of the aftermarket pad (AM). In addition, the presence of copper was also found in an OE brake pad which usually is deposited on roadways and then gets transported to lakes and rivers by storm water runoff, thereby contaminating the water bodies. The paper also includes some suggestions to prevent the heavy metal contamination. The study recommends that strict legislations needs to be enforced to monitor the usage of heavy metals and banned contaminants in the formulation of brake pads. Additionally, the study proposes to make some basic product testing standards for brake pads to pass certain fitness level/with fade indices under varying conditions before it gets delivered in the market in order to ensure safety levels in Indian Market and to protect waterways by ensuring brake pads are free of toxicants.

1. Introduction

Brake pads are vital components in an automotive system. An ideal friction material is expected to have good fade resistance, moderately low wear, rotor friendliness, good pedal feel, low vibration and noise, emit no toxic materials and low cost. A monolithic material would not be able to support these multitude properties and hence it requires a medley of components. These components are classified as binders, fibers, functional additives/abrasives and fillers (Bijwe, 1997; Chan and Stachowiak, 2004; Xiao et al., 2016). Significant quantum of work had been carried out in the past by researchers worldwide to demonstrate the influence/importance of these components to optimize the frictional

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performance which ultimately gives control to the drivers and safety to both drivers and pedestrians. Vehicular traffic causes the accumulation of contaminants on road and parking lots. Wear debris from tires, brake system and clutch linings contribute to increase in measure of sediment particles and toxic heavy metals. Various environmental protecting agencies are concerned mostly about point sources like pollution products from automotive industries, chemical factories, electronic & electrical industries, fertilizers and mining's only. However in reality, the actual threats are from the non-point sources which include wear from brake pads and tires of automotive vehicles.

Looking at the statistics, it has been observed that globally 70.5 million passenger cars were produced in 2018. A similar trend has been witnessed in India also as the quantity of passenger cars produced increased from 2.05% in March–April 2019 compared to the same last year and it appears that India is on the verge of becoming a major producer of passenger vehicles (society of India automobile manufacture). This increase in vehicle production would ultimately fuel the demand for brake friction market as it is closely related to production and sale of cars. Further, the increased usage of brakes due to traffic congestion increases the demand for replacement units. Indian automobile market is primarily driven by a large number of small and medium firms in this unorganized sector. Specifically, northern and western regions of India contribute to be the leading contributors in the market, and collectively account for more than 56% volume share in the country's brake pads and linings market in year 2017. Moreover, recently it was announced by the ministry of Indian transport that by the year 2022, all commercial automotive vehicles will be fitted with Advanced Driver Assistance System (ADAS).

As per Govt. of India, ministry of statistics and programme implementation around 21 crore motor vehicles appear and move on road and several thousand tons of brake wear debris could be emitted every year in India. However, there appears to be no clear information on the different types and nature of contaminants that are released. The reason owing to this is that different manufacturers use different formulations which would ultimately lead to increasing concerns over their potential effects on human health and the environment. Soil is a major sources for transporting heavy metals, soil and heavy metals have strong and diverse binding characteristics. In spite of this, unlike organic pollutants, metals do not biodegrade, but bio-accumulate in the environment. Soil matrix may adsorb exchange, oxidize, reduce, catalase or precipitate metal ions. This depends on several factors such as: moisture content, pH, and temperature, nature of metal, particle size distribution, and clay content. These parameters play an important role in the solubility, mobility and toxicity of heavy metals in soil.

R and D division of OE manufacturers conducted many controlled environment lab tests and on-road tests in order to validate the safety aspect. This involved quite a lot of investment. There by it is inevitable to have reasonable prices of their brake pads. In contrast, the aftermarket brake pads could sell their product at half the price of OE brand because of the elimination of costly test procedures and with the inclusion of cheaper banned components. There is no assurance that the latter pads would pass the fitness level if rigorously tested as per standard industrial norms. It should also be noted that just through visualization one may not be able to distinguish the product from the two manufacturers.

The performance of aftermarket brake pads has also been studied worldwide. All aftermarket brake pad manufactured in US were tested to Federal Motor Vehicle Safety Standard No. 135. Top three aftermarket brake pads were selected from the evaluated samples and they were fitted in police vehicle models and on road tests were conducted. It was observed and concluded from these tests that aftermarket brake pads were unable to address the issues of wear, noise or chemical compositions in their formulations including heavy metals.

This paper deals with the aims to apply safety index to compare relative safety of disc brake pads and to check their mineralogical composition (OE and aftermarket) sold in India. Three brake pads were selected from the market. They included highest selling OE brake pad, (Semi-metallic) in the Indian market and two different aftermarket brake pads one used for export AM (E) and other for Indian roads AM with differing costs. The pads were initially screened as per the minimum regulations/standards (SAEJ661/IS 2742). Heavy metals present in the brake pads were also analyzed. In addition, asbestos (toxicological critical fibers) identification test were also carried out on all the three brake pads. This study is vital for the reason that to ensure the aftermarket pads sold pass the minimum fitness levels approved by the government regulations to ensure safety level. Moreover, National as well as international co-operation must frame proper guidelines to avoid heavy metal content entering the waterways. Hence the objective of this work is impact on study about Safety and Environmental Aspects.

2. Literature survey

Fono-Tamo et al. (2015) examined the tribological properties especially the wear from four aftermarket brake pads that are sold in Nigerian market using Weibull approach. Comparative study of three aftermarket brake pads from Brazilian market concluded that the performance of two brake pads were satisfactory and as per standards whereas the third one could not achieve a minimum level of safety index in terms of parameters analyzed (Neis et al., 2016). (Omar et al., 2018) evaluated two brands of brake pad sold at low price and compared it with an OE brake pad and found that one of the low price pads performance was near to that of OE while the other brake pad exhibited higher wear loss. Further study relates the different brake composition of Malaysian automotive aftermarket pads with price variation (Omar et al., 2016).

None of the authors mentioned above checked for the presence of any hazardous ingredients in the formulation of those brake pads as their work mainly focused on the wear and frictional performance. Even after the ban of asbestos fibers, various toxics like heavy metals were still found to be utilized. The other raw materials in the brake pad needs to

Table 1
Comparative analysis of existing approaches.

Author	Methods	Results	Disadvantages
Fono-Tamo et al. (2015)	Evaluated the wear properties of four brands of brake pad available in the Nigerian market	From the analysis results, we can make the following conclusions: sample TY exhibited the highest hardness value (29.09) and sample SN the lowest (10.05).	Overall performances of Nigerian brake pads do not meet all the specifications for friction materials used in road vehicle brake linings and pads
Wahlström (2016)	Investigation of the effect of different parameters of the pad friction material on the coefficient of friction and wear emissions.	The simulated result indicates that a stable third body, a high specific wear, and a relatively high amount of metal fibers yield a high and stable mean coefficient of friction, while a stable third body, a low specific wear, a stable resin, and a relatively high amount of metal fibers give low wear emissions.	This has several disadvantages, like the cells have a fixed size and shape. The dynamics can be influenced by grid effects which affect the performance
Chowdhury et al. (2012)	friction coefficients of different material pairs are investigated and compared Friction coefficients of different material pairs are investigated	Results reveal that friction coefficient decreases with the increase in normal load for all the tested pairs. On the other hand, it is also found that friction coefficient increases with the increase in sliding velocity for all the material pairs. The magnitudes of friction coefficient are different for different material pairs depending on sliding velocity and normal load.	There is some performance degradation if it is applied to the real time applications.

be more environment friendly and non-carcinogens as classified by International Agency for Research on Cancer (Jang and Kim, 2009). The wear debris generated in dynamometer test for semi metallic and low metallic automotive brakes found numerous micro/nanoparticles of different compositions tested among rats and found them to be toxic (killing bacterial cells of rats) (Kukutschova et al., 2009; Kukutschová et al., 2010, 2011) studied the impact of wear debris particles on environment and proposed brake manufacturers to develop safer products. Recently many countries paying increased attention on the effect of wear debris Particulate Matter (PM) polluting the environment and its effect on human health (Guttikunda and Goel, 2013; Ciudin et al., 2014; Lukić and Miloradović, 2016; Perricone et al., 2018; Romeh, 2018; Valotto et al., 2019).

DFG commission established MAK and BAT values 2018 for the toxicological substance present in the work place ingredients like alkaline oxide and alkali earth oxide (Na_2O + K_2O + CaO + MgO + BaO), heavy-metals (cadmium, chromium, lead & lead compounds), mercury and other inorganic/organic compounds containing antimony, carbon black, and respirable fibers.

Moreover, heavy metals appearing in the environment gutter and goes through storm water and potentially discharges into waterways which have biological effects in the life's of invertebrates in water. Besides, green ingredients used in formulation upon its utilization in brake cushion could emanate/change over into dangerous gases. For instance, Antimony tri-sulfide Sb_2S_3, over 860 °C can be changed over into Antimony trioxide Sb_2O_3 which is considered as cancer-causing (Amato et al., 2012). To reduce the effect of heavy metal content in the environment due to the wear of brake, Eco friendly brake pads are developed by replacing fully are partially by natural fibers (Yun et al., 2010; Idris et al., 2015; Aranganathan and Bijwe, 2016; Ahmed et al., 2019; Rajan et al., 2018a, 2019a; Md et al., 2019; Rajan et al., 2019b,c). Here Table 1 shows the comparative analysis of the various approaches.

3. Experimental methods

Three brake pads were procured from the market. The first one was the high selling OE brake pad (OE) (Rs 1580/- it consists of 2 sets of brake pad — 04 pieces). Second one was from a renowned aftermarket manufacturer (AM (E)) which had a superior quality and was priced Rs. 780/-. The last one was from a local market which was readily available in all the service stores (AM) and its cost is Rs. 500/-.

The physical, chemical and mechanical properties are performed as per test standards which are listed below. In addition, as per United Nation Regulation, a minimum physical compulsory specification is insisted that requires all brake pads meets the minimum values of shear, cold and hot compressibility test.

Table 2
Physical, Chemical and mechanical properties of the three brake pads.

Parameters	O.E	AM(E)	AM
Density (g/cm^3)	2.12	2.17	2.23
Hardness (S-scale)	90, 94, 93, 93, 91	85, 88, 85, 89, 87	80, 81, 80, 84, 83
Cold Shear strength (kg/cm^2)	35, 32, 34, 32	30, 30.8, 32, 31	29, 30, 32, 30, 31
Porosity (%)	6.1	6.4	9.2
Thermal conductivity (W/(m K))	2.34	2.12	1.67
Heat swell @200°C (mm) electric oven	0.045	0.051	1.1
Water swell @ room temperature	Nil	Nil	Nil
Loss of Ignition@850°C(%) (Muffle furnaces)	17.06	22.30	26.88
Acetone extraction (%) (Sohlacet Apparatus)	0.33	0.42	0.66
Cold compressibility (Max 2%)	1.8	2.1	2.2
Hot Compressibility (250 °C)	4.4	4.6	4.7

The amount of force required to separate the brake material from the metal backing plate is called shear strength. The requirement as per industrial standard is a minimum 25 kg/cm^2. Compressibility test ensure the change in thickness of the pad for maximum pedal pressure. The order for cold and hot compressibility (at 400 °C) is maximum of 2% and 5% respectively. Products not meeting the above requirement are considered as not safe for the brake application. As seen from the Table 2, all the brake pads possessed the minimum physical properties. Porosity, thermal conductivity and LOI are higher in the case of AM which is undesirable which reflects the friction behavior during vehicle run. Since, the formulation of all the three brake pads are unknown, the exact reason for the same could not be concluded.

4. Results and discussion

The Fig. 1 depicts performance of pads in all the testing modes. The detail description of the test schedule can be seen elsewhere (Balaji and Kalaichelvan, 2013). Baseline mode refers to our normal driving condition in plain roads. Almost all the three brake pads performed well. Fade mode is critical in evaluating the friction material as brake pads are rated in the market by their resistance to fade. Fade is the loss of brake effectiveness particularly, at elevated temperatures (Balaji and Noorani, 2019). The curve in the graph should be as straight as possible without any waviness for an ideal friction material. Fade occurs normally when situation demands continuous braking/drag at frequent intervals similar to the case of descending in a hilly terrain.

In the case of OE, no trace of reduction of μ can be identified. The curve is almost straight showing its superiority. In the case of AM (E), even though there is a drop in both the fade 1 and fade 2 cycles, the lowest μ recorded is 0.42 and 0.36 respectively. During fade 2 unwanted disturbing noises are also heard. For AM, there is drastic reduction of μ revealing its poorer fade resistance. Since, the formulation is unknown, the real reason behind this could not be found. The lowest μ recorded during fade 1 is 0.27 and during fade 2 is 0.32. This performance is below par as per industrial standards. Moreover, AM produced lot of brake dust which necessitates cleaning of rotor.

The wear test is carried out using Inertia brake dynamometer Fig. 2 following JASO C 427 method. Wear test was carried out rigorously in order to estimate the life of the pads. The detailed test schedule for wear test is explained elsewhere (Rajan et al., 2018b). The wear loss is expressed as difference in mass (g) and thickness (mm) of the brake sample before and after test. Samples do not wear linearly at different stages of operation however Fig. 3 represents the wear loss due to mass and thickness variation of the sample. The highest wear was observed in AM (68.3 g) compared to AM (E) (56.9 g) and OE (54.3 g) exhibits lowest wear loss. Lowest thickness loss is observed in OE (1.168 mm) which is similar to the results obtained by (Lee and Filip, 2013), where the thickness loss of the baseline material is less compared to other samples under dynamometer testing (Rajan et al., 2019a; Sathickbasha et al., 2019a). The thickness loss of AM(E) is (1.219 mm) and AM is (1.422 mm). The thickness loss is related to different shape, size, type, and percentage of components used in the friction material, including the friction layer of tested brake pads. The average thickness loss is not contributing directly to fade temperature, but organic components of friction material related to the average thickness loss (Jaafar et al., 2008). AM has higher wear than AM(E) and OEM performs the best. Work shows wear loss is not linear at different stages of operation and in most of the cases the thickness loss in higher compared to the mass loss except at elevated temperature due to the breaking of organic components. In addition, minimum thickness loss of brake pads can be achieved by the small size and shape of constituents. Fig. 4 shows the worn surface of the brake pads after testing.

In general, AM pads scored poorly in wear due to mild stress cracks, glazing and discoloration. AM(E) and OE pads scored good in wear due to almost negligible structural cracks, Grooves, Glazing, Pitting, Blisters, Edge Chipping and Discoloration. The Fig. 5 shows the ecological rankings for non-exhaust emissions of heavy metals provided by the European Environment Agency EEA2018.

United States Environmental Protection Agency prepared a Metals Risk Assessment report that addresses the special attributes and behaviors of metals and metal compounds to be considered when assessing health and ecological risks.

There is still some confusion regarding which are all termed as heavy metals. Heavy metals can be identified with the specific gravity at least five times more than water. Their placement on the periodic table is important in understanding

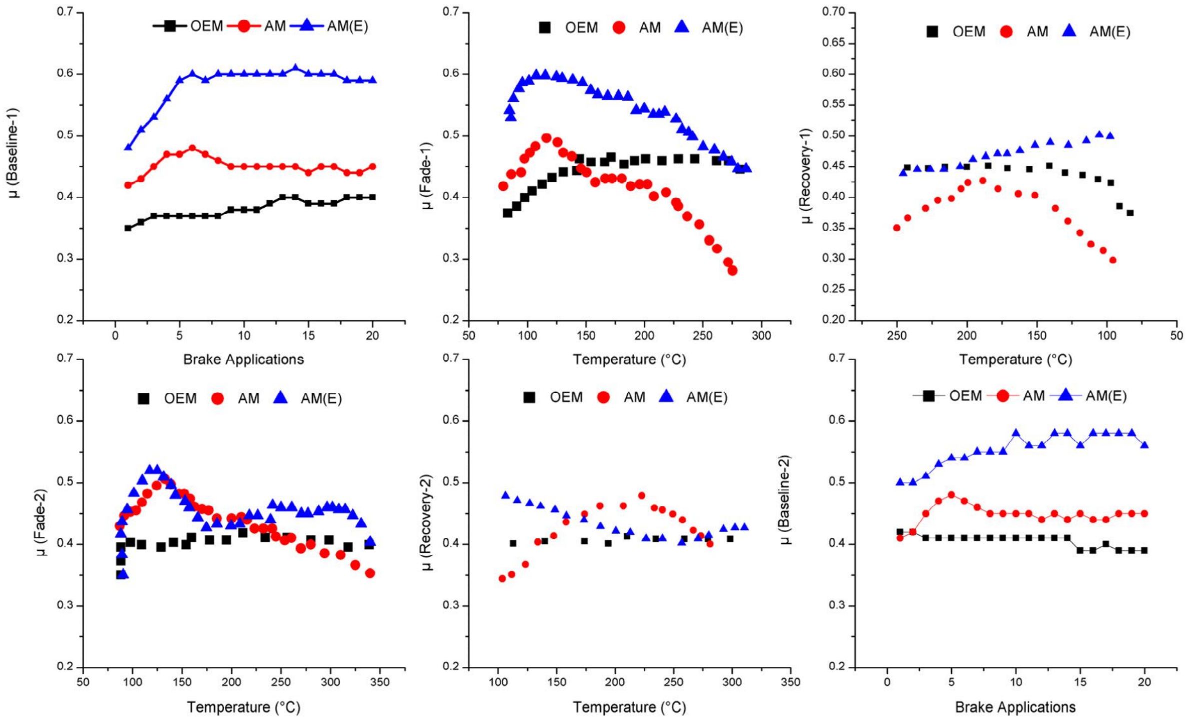


Fig. 1. Frictional Performance (Initial Screening of Brake Pads based on SAE J661 Standards) (a) Baseline 1 (b) Fade 1 (c) Recovery 1 and (d) Fade 2 (e) Recovery 2 (f) Baseline 2.

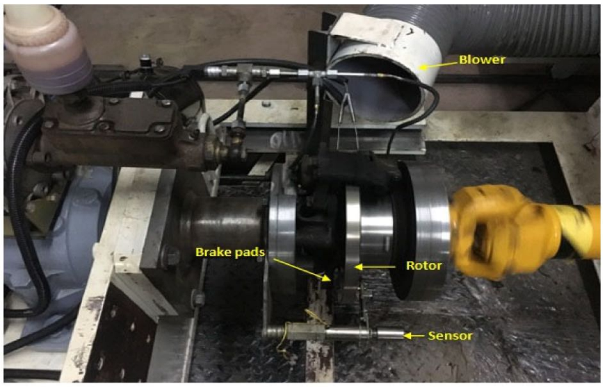


Fig. 2. Dynamometer Setup with the Brake Pad Assembly.

their chemistry. These heavy metals have an atomic number greater than 20. This list excludes alkali metals and alkaline earths.

Heavy metals are common sources of soil pollution by road runoff from cars Fig. 6. Soils polluted with heavy metals will cause damage to crops and other food sources (Valotto et al., 2019). For example, heavy metals increase toxicity levels by entering into the soil and surrounding plants (Romeh, 2018).

The brake pad normally contains chromium and nickel in stainless steel, copper (an indispensable metal) for its excellent thermal conductivity, antimony from the metal sulphides Cheaper solid lubricant for minimum stopping distance (Sathickbasha et al., 2019b,c) and sometimes lead.

The presence of mercury and cadmium are rare. But recent researchers have identified nickel and titanium as an alternative for copper (Yun et al., 2010) and hence the possibility of those metals in the brake pad is also not negligible.

The application of brakes on the automotive passenger cars releases fine particles of metals particularly copper due to wear caused by friction and deposited on the roadways which are then washed during raining to the lakes and rivers. The non-point source of storm water runoff from roads has the impact on Survival of *Salmon fish* species (Sandahl et al., 2007).

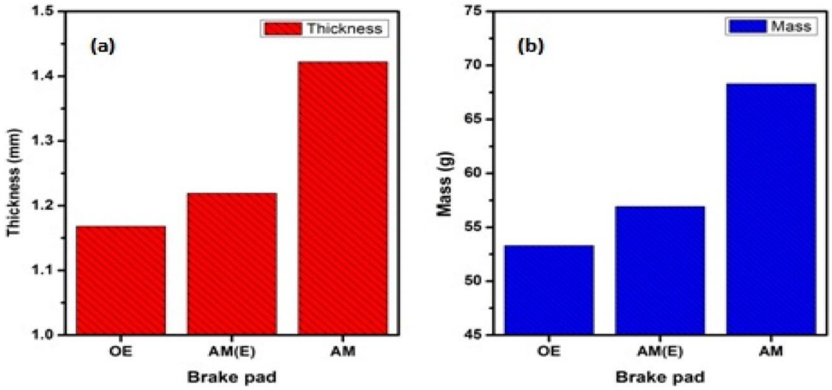


Fig. 3. Wear of Brake Pads (a) Thickness Loss and (b) Mass Loss.

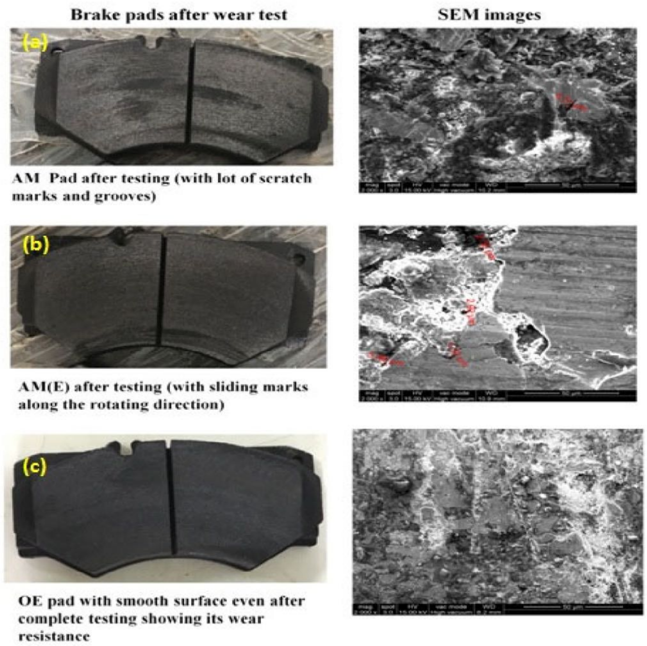


Fig. 4. Worn Surface of the Brake Pads after Testing.

As it is difficult to further break these metals, this metal will be in the waterways forever. These heavy metals (particularly copper), at higher concentrations have toxic effects that can be severe for invertebrates in water. standard renewal bioassay methods is used to assess the toxicity of Zinc and Copper on the fish *Puntiusparrah*, and the 96-h LC_{50} values of zinc and copper were 9 mg/L and 0.5 mg/L, respectively (Ciji and Nandan, 2014).

The author revealed that the combined effect of copper and zinc causes severe cellular damage resulting in biochemical and hematological changes at sub lethal concentration in fishes. Compared to other sources, wear of brake linings/pads is a significant source of copper and lead (Westerlund and Johansson, 2002).

4.1. Testing for heavy metal presence

To check for the heavy metal content, the wear debris collected from the chase test is taken. The debris of size more than 20 μm is selected and checked using SEM with EDAX. From the table, it can be observed that none of the carcinogenic elements like cadmium, lead and antimony is present in any of the brake pads. Perhaps all have moved to environmental friendly metal sulphides. Copper being expensive and an indispensable ingredient was found in OEM and hence comes under ECO-1,2 &3. AM(E) being an export product is devoid of all the environmentally banned items. But, AM has a trace of asbestos, a banned toxicological fiber.

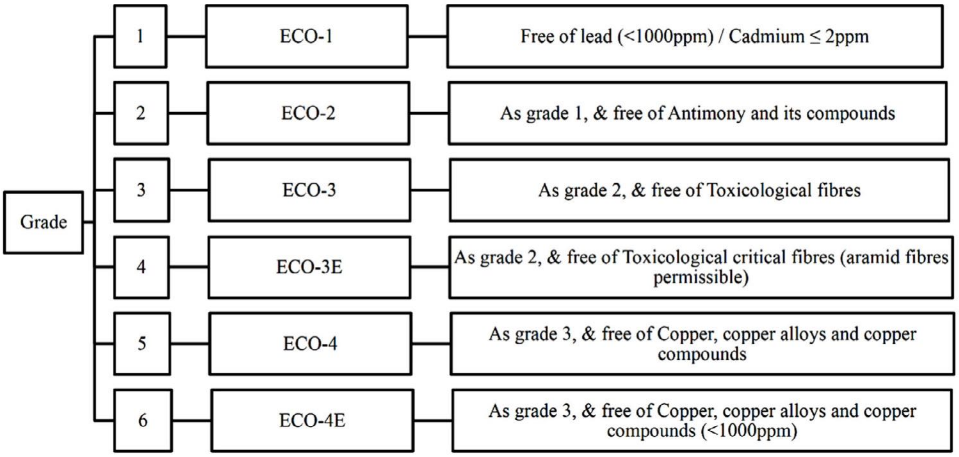


Fig. 5. Grade Ranking of Metal and Toxicological Compound Present in the Brake Pad.

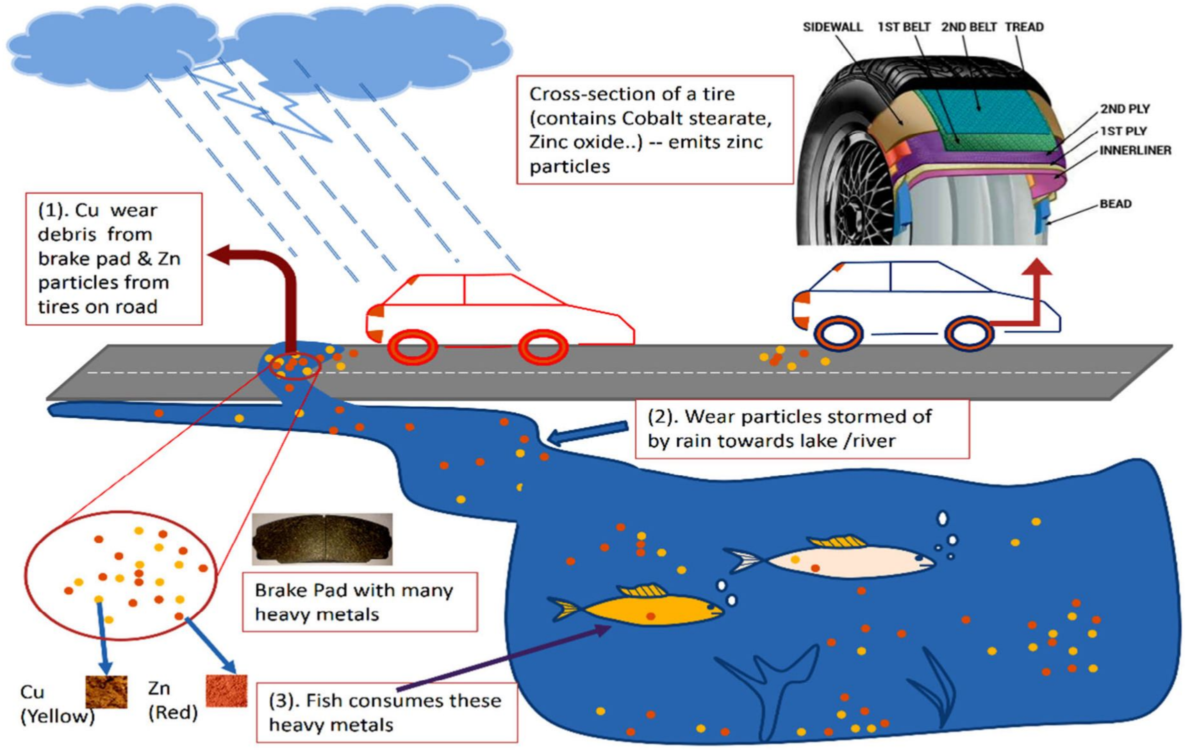


Fig. 6. Heavy Metal Contamination in the Soil and Water.

As per California Senate Bill (2010), 0.5% Copper is permitted up to 2025. The key to controlling heavy metal pollution lies with the formulators. But, the fluctuation and rise of copper price will definitely force the formulators worldwide to find an alternative for copper and its alloys and hence, OE pads will be devoid of copper in the near future. Prevention is better than cure dealing with the metal concentration in the waterways is difficult than preventing the same in entering. Efficient management studies are required to arrive the same. Table 3. Shows the heavy metal content in the OEM,AM (E),AM wear particles.

Even though, the asbestos is banned, its trace is sometimes possible in vermiculite and from other mineral fibers. Work carried out by (Mokhtari et al., 2019) shows that the presence of asbestos fibers in the area Yazd (9.51 fber/l)is higher than the WHO (9.51 fber/l). Hence asbestos identification test is also carried out with the Computerized/Digital Polarized

Table 3
Heavy metal content in the OEM, AM (E), AM wear particles.

Main Constituents XRD	Metals	OEM	AM (E)	AM
Iron	Fe	✓	✓	✓
Aluminum	Al	✓	✓	✓
Copper	Cu	✓	–	–
Magnesium	Mg	✓	✓	–
Chromium	Cr	✓	–	–
Cadmium	Cd	–	–	–
Calcium	Ca	–	✓	✓
Tin	Sn	–	–	–
Barium	Ba	–	✓	–
Zinc	Zn	–	–	–
Silicon	Si	✓	✓	–
Manganese	Mn	–	–	✓
Antimony	Sb	–	–	–
Potassium	K	✓	✓	✓
Zirconium	Zr	–	–	✓
Titanium	Ti	✓	–	✓
Lead	Pb	–	–	–
ECO-Rank		ECO-1, 2 & 3	ECO-1, 2, 3 &4E	ECO-1, 2 &4E[a]

[a]Toxicological fiber namely asbestos is identified in AM which is detailed in the next section.

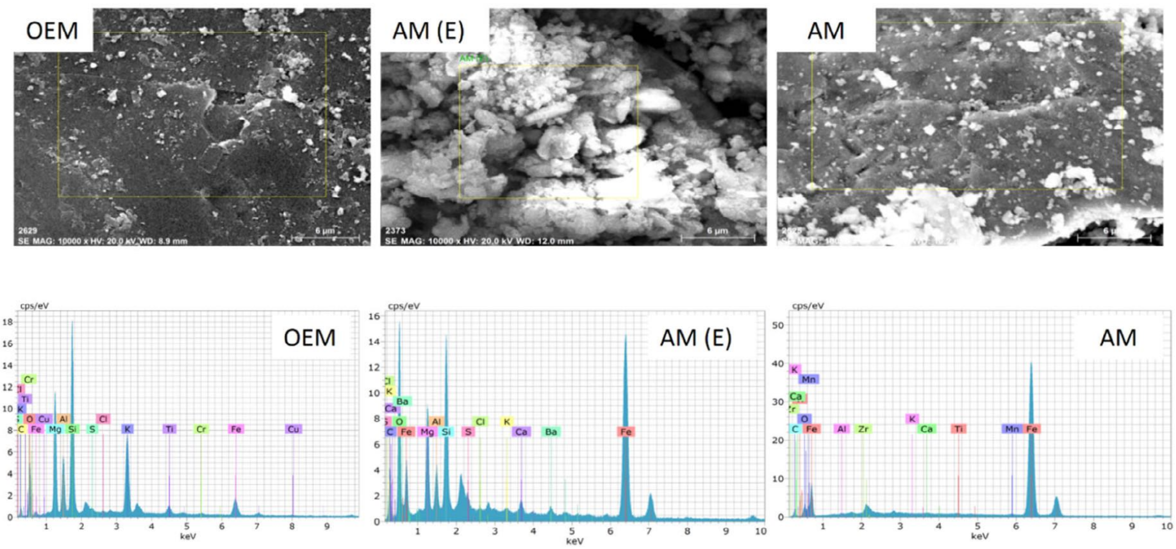


Fig. 7. SEM and EDAX of OEM, AM (E) and AM.

Microscope, Stereo Microscope, and Dispersion Staining Analytical apparatus conform to standard ISO/DIS 22262- Part 1. Fig. 7 shows the SEM and EDAX image results.

4.2. Prevention of heavy metals

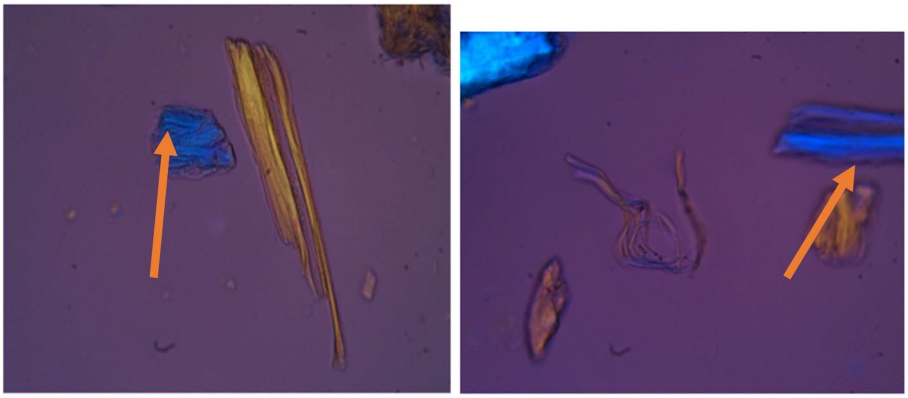
The primary and cost-effective method of treating these heavy metals is source reduction. As said earlier, sustainable components could be utilized in production of brake pads which would contribute to lesser pollution. Alternatively, to address the issues of increasing contamination, monitoring samples to have detailed characteristics would give an in depth ideas of their distribution in water ways and soil media.

4.3. Asbestos identification test

As can be seen from Fig. 8 asbestos is identified in the AM. Observation of the following characteristics for the fiber under consideration shows:

First Identification is somewhere at the edge, Broome shaped or bundle of fibers together

Second identification is the polarization effect which shows the change in color whenever the slide is rotated; it means it is behaving like a crystal by showing two different colors while seen in different wave lengths. This unique crystalline behavior can be observed only in asbestos fiber while other fibers show same color while rotated.



a b

Fig. 8. PLM Micrograph of AM Brake Pad Fibers at Two Different Orientations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

OEM and AM (E) did not show any trace of asbestos. Since the performance of AM is inferior when compared to the other two brake pads, it can be concluded that the asbestos may not have been deliberately added. The presence of asbestos may be from some other impure mineral fibers used in the formulation.

5. Conclusion

In this work a model of disc brake pads is analyzed with simple geometry. New materials like composite, heterogeneous, dynamic etc. can be tested to see the effect on the temperature distribution in the brake disk. The potential, elastic and plastic energy transformation may be included for more precise analysis. Presence of heavy metal was observed in all the three types of brake pads which appears to be quite alarming from the environmental point of view. Here the OE pad was found to perform better with respect to friction and wear. AM(E) provided adequate performance However, AM performance was not satisfactory from safety point of view. Moreover, it was also found to contain asbestos trace. Then Wear resistance was poor in case of AM (E). Since the formulation was not known, the exact reason for the same could not be found. The non-point source of wear from brake pad was a serious concern which needs to be addressed at with national and international level. Hence the Efficient monitoring and management studies are required to deal with the metal concentration in the waterways. In future the brake pad/lining formulation may radically change to improve the environment and public health. Future research directions proposed prescription in the recipe to increase the friction coefficient. The study led to that of real time application for the light and medium weight vehicles brake pads.

CRediT authorship contribution statement

P. Baskara Sethupathi: Methodology, Software, Data curation, Writing - review & editing. **J. Chandradass:** Conceptualization, Methodology, Software, Data curation, Writing - original draft, Writing - review & editing, Validation. **M.A. Saibalaji:** Methodology, Validation, Writing - review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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