How To Minimise The Harmful Impacts Of Brake Wear Pollution On Health And The Environment.

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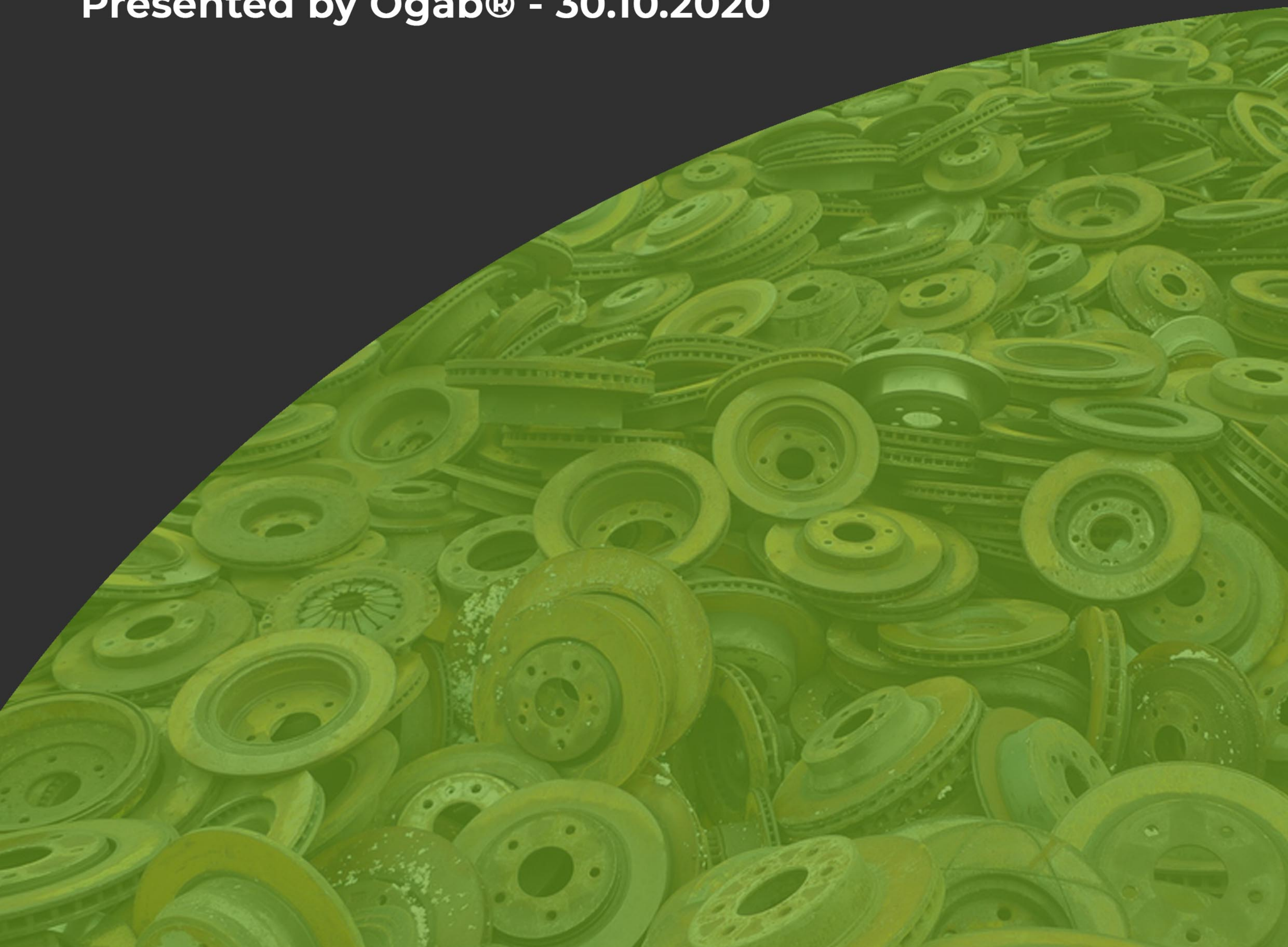

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1. Introduction

The discussion surrounding society's environmental impact continues to grow. Not only is the debate centred on the human effect on the environment, but also how a poor environment can adversely affect the health of humans and wildlife too.

Pollution is a significant cause for concern. With air pollution considered one of the world's leading risk factors for mortality, attributing to 9% of global deaths. (Ritchie, 2017)

With recent events in the modern world, namely, the Coronavirus pandemic, there has been a renewed importance on ensuring that we continue our battle against environmental pollution. This is to secure not only the safety of the environment but also for the health of the population.

One major contributor to pollution is the transport industry. This includes road, rail and aviation. In the UK, transport is the most polluting sector, contributing to 26% of greenhouse gas emissions. (Independent, 2018)

One aspect of transport pollution which is often overlooked is the impact of the wearing of brake discs. Brake pad ingredients and components are considered trade secrets, while the industry overall is largely self-regulated. This means research into this field is somewhat limited. Consequently, this report hopes to shed light on the causes and solutions of brake wear pollution and expand this area of research.

This report will discuss the effects of brake disc wear on the environment and therefore, on health. To do this, it will first be necessary to analyse, using statistical data, the environmental impacts of brake disc wear and particulate matter. The report will then move on to use this analysis, to discuss the impacts that this data presents for various health conditions, including Coronavirus.

It will then conclude that brake discs through its particulate matter, has a significant impact on air pollution, mineral resources scarcity, water pollution and the world's carbon footprint. Therefore, it is vital that we continue to research into new technologies to improve the efficiency of brake discs, so that we may be able to continue our fight against environmental degradation and protect the future population from poor health. Ultimately, to improve the quality of life for much of the world's inhabitants.

2. Particulate Matter from Brake Wear

First then, let us define what we mean by particulate matter and brake wear, so that we may better understand the relationship between the two.

Brake wear: *Standard frictional brakes on a vehicle function by virtue of the friction between a brake pad and a rotating disc or drum when the two are forced together by application of pressure to the braking system. The frictional process causes abrasion both of the brake pad and of the surface of the disc or drum leading to the release of particles, a substantial fraction of which become airborne. (DEFRA, 2019a)*

Particulate matter (PM): *The emissions consisting of particles suspended in the air. For example, sea salt, black carbon from combustion, dust, and condensed particles from certain chemicals. They are measured, according to the particle diameter size, as PM10 (diameter less than 10 micrometres), PM2.5 (less than 2.5 micrometres), and UFP (Ultra Fine Particles, less than 0.1 micrometres).*

Particles emitted as a result of transport activity can be distinguished according to their source into:

- **Exhaust traffic-related particles** - emitted as a result of incomplete fuel combustion and lubricant volatilisation during the combustion procedure.
- **Non-exhaust traffic-related particles** - generated from tyre, brake, clutch and road surface wear. Alternatively, the particles may already exist in the environment as deposited material and become resuspended due to traffic-induced turbulence, tyre shear and the action of the wind.

Now that we have defined the terms, particulate matter and brake wear, it becomes possible to have an in-depth look at the statistical data for the three main transportation networks (Road, Rail and Aviation).

By doing so, the report aims to provide insight into the environmental impact of brake wear through its continued inefficiency in the three main modes of transport.

2.1 Brake Particulate Matter Emissions in Road Transport

Approximately 50% of PM emissions from a car are non-exhaust particles, and of the non-exhaust PM, about 50% originate from the brake discs.

Brake emissions are the most significant non-exhaust emissions of road vehicles, particularly in areas of high traffic density and braking frequency.

Image 1: Visual of a brake disc reaching excessive temperature levels.

In urban environments, brake wear can contribute up to 55% by mass of total non-exhaust traffic-related PM10 emissions and up to 21% by mass to total traffic-related PM10 emissions.

Urban environments typically see the highest results in traffic-related emissions, while in freeways and rural areas this contribution is reduced due to lower braking frequency.

Table 1 Emission factors of PM10 from tyre and brake wear and road abrasion. Source: DEFRA, 2019a

Vehicle	Type of road	Emission factors for PM10 (mg PM10/km)		
		Tyre wear	Brake wear	Road abrasion
Car	Urban	8.7	11.7	7.5
	Rural	6.8	5.5	
	Motorway	5.8	1.4	
LGV	Urban	13.8	18.2	7.5
	Rural	10.7	8.6	
	Motorway	9.2	2.1	
Rigid HGV	Urban	20.7	51.0	38.0
	Rural	17.4	27.1	
	Motorway	14.0	8.4	
Artic HGV	Urban	47.1	51.0	38.0
	Rural	38.2	27.1	
	Motorway	31.5	8.4	
Bus	Urban	21.2	53.6	38.0
	Rural	17.4	27.1	
	Motorway	14.9	8.4	
Motorcycles	Urban	3.7	5.8	3.0
	Rural	2.9	2.8	
	Motorway	2.5	0.7	

To put this in perspective, the average vehicle in a Swedish urban area emits 60 mg PM10 per km, considering both exhaust and non-exhaust emissions (Ferm and Sjöberg, 2015). Consequently, the non-exhaust particles emitted from tyre and brake wear as well as road abrasion have a significant contribution to the PM10 emissions of a vehicle.

98% (by mass) of airborne brake wear particles can be classified as PM10. 40% of the PM10 is PM2.5, 10% is PM1, and 8% is PM0.1.

It is estimated that only 7% of PM2.5 pollution from traffic comes from tailpipe exhaust fumes at roadside sites. The rest comes from sources such as tyre, clutch and brake wear, as well as the resuspension of road dust.

Perhaps surprisingly, brake dust is the source of 21% of total PM2.5 traffic pollution. These are particles small enough to be inhaled into the deepest regions of the lung. Dust from brake friction is rich in metals, which can catalyse the production of reactive oxygen species; chemicals which can cause damage to cells on entering the lungs.

Particles And Human Health

Furthermore, metal particles of this size from the abrasion of brake pads may cause inflammation and reduce the ability of immune cells to kill bacteria, similar to particles derived from diesel exhausts. This is why the chemical characterisation of brake wear dust is important when considering its impact.

It is important to note that the dust composition will depend on the manufacturer, the application (car, train, etc.) and pad properties. However, studies show that the most important chemical constituents of brake wear are;

- Fe (iron) with a contribution of up to 46%
- Cu (copper) with a content of up to 14%
- Organic material with 13%
- Other metals, including Pb (lead) (~4 %), Zn (zinc) (~2 %), Ca (calcium) and Ba (barium).

In the next table, the concentration ranges of elements found in brake wear dust are shown based on the literature review done by Grigoratos and Martini (2014). It indicates that the concentration of each element can significantly vary, but in each case, the most prominent element is iron.

Table 2 Trace element concentrations found in emitted brake wear dust. Source: Grigoratos and Martini, 2014

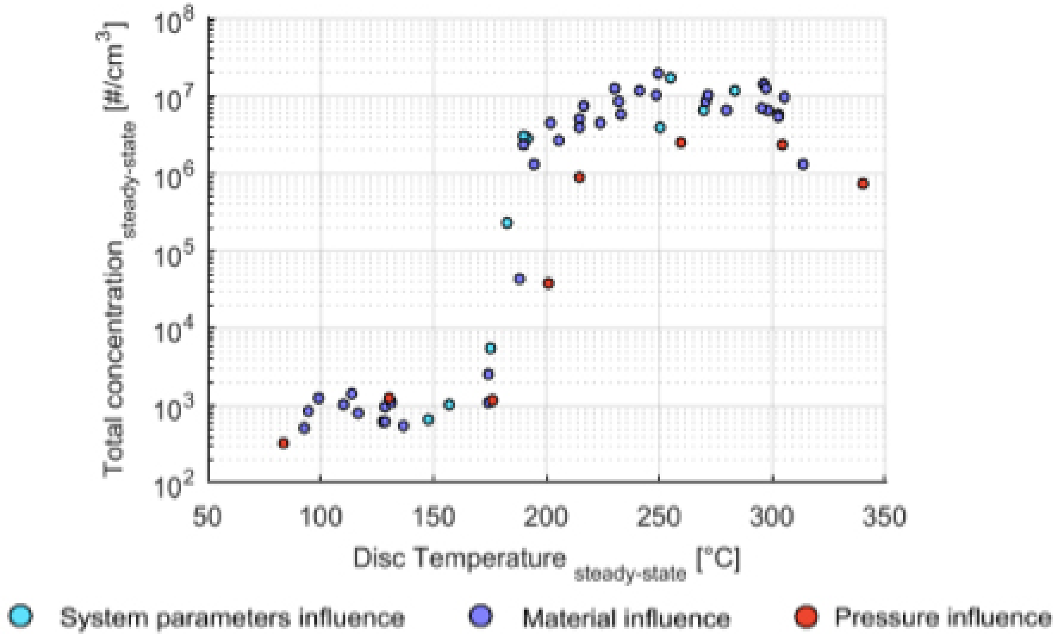
Metal	Brake dust (mg/kg)	Metal	Brake dust (mg/kg)
Al	330–20,000	Mg	(1700)–83,000
As	<2.0–(110)	Mn	620–5640
Ba	(5800)–140,000	Mo	5.0–740
Ca	500–8600	Na	80–(5100)
Cd	<0.06–11	Ni	80–730
Co	12–42.4	Pb	4.0–1290
Cr	135–12,000	Sb	4.0–19,000
Cu	70–210,000	Sn	230–2600
Fe	1300–637,000	Ti	100–110,000
K	190–39,000	Zn	120–27,300

Values in brackets refer to PM_{10} brake wear (Hildemann et al. 1991; Garg et al. 2000; Kennedy et al. 2002; Westerlund and Johansson 2002; Kennedy and Gadd 2003; Sanders et al. 2003; Von Uexküll et al. 2005; Schauer et al. 2006; Iijima et al. 2008)

The wear will typically produce relatively coarse airborne particles. However, the temperature can cause some variations, as it is shown in Figure 1 below. Higher temperatures associated with brake components will typically promote the generation of ultrafine particles and increase particle concentration.

Furthermore, the emissions will increase by several magnitude orders in the range 170-200°C. An additional consequence of the temperature increase is a progressive shift in size distribution towards the ultrafine fraction.

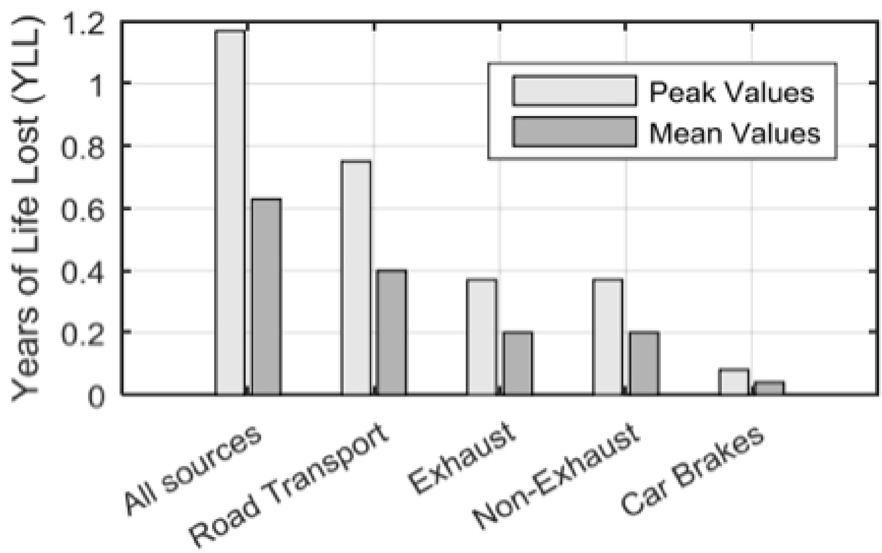
Figure 1 Transition temperature of a disc for different testing conditions and concentration of particles. Source: Alemani, 2017.



The emission of particulate matter can be linked to a reduction in life expectancy, due to health effects, such as cardiovascular and respiratory diseases and cancer.

Alemanti (2017) estimated Years of Life Lost (YLL), an indicator to evaluate the reduction in life expectancy, due to PM emissions.

Figure 2 Years of Life Lost (YLL) in European urban areas due to different PM sources. Source: Alemani, 2017.



According to Alemani, the mean life expectancy in European urban areas is reduced by 0.63 years per person, with peaks of 1.2 YLL. Brake particulate matter in Europe is responsible for 0.043 YLL per person on average (i.e. 16 days of life lost), with peak values up to 0.08 (i.e. 27 days of life lost), as shown by Figure 2.

EVs and the Zero Emission Mistruths

With the loss of life due to air pollution in mind, it is important to be aware of the misleading information promoted by both automotive manufacturers and international governments in relation to electric vehicles.

It is often assumed incorrectly by the public due to this misinformation that in future years electric vehicles will create a 'zero-emission' solution to road vehicle pollution, this is not the case.

Encouraging more people into electric vehicles is at the heart of the UK and EU countries government's efforts to tackle climate change. However, this is, in fact, a 'zero-emission' fantasy because in reality, with current technology, it is impossible to achieve zero emissions.

With the introduction of EV's in recent years, there is limited data available, particularly concerning brake wear. Electrical vehicle brake wear is equally damaging as brake wear from petrol-fuelled vehicles, although it is not reflected in the data in this report.

This means that the damaging impact we give evidence of is even more significant when electric and hybrid vehicles are also considered in the ill-effects of brake wear on human health, the environment and its inhabitants.

This is further compounded by the fact that non-renewable energy sources account for 65% of electricity generated worldwide. This forms the carbon footprint for charging electric vehicles and only adds to the emissions that are already released from tyre and brake wear, which gives further evidence against these vehicles being zero-emission.

Many governments, including the UK as well as EU councils, often offer tax relief and other incentives to promote these pollutant cars despite the information being misleading and inaccurate.

Transparency from both manufacturers and government bodies is required in order to provide reliable data around electric vehicle emissions. The policy must be changed to stop the false claims that that are currently promoted to the mass population.

2.2 Brake Particulate Matter Emissions in Rail Transport

In rail transport, non-exhaust particle emissions are produced by the abrasion of brakes, wheels, and rails.

Image 2: Rail transport brake failure.

Gehrig et al. (2007) made measurements at various distances from an electrified rail line in Switzerland. At around 10m from the trackside, PM10 concentrations were found to be around 1 μg/m^3 above that measured at a nearby background site.

The PM concentrations were dominated by Fe (iron) with smaller contributions from Cu (copper), Mn (manganese) and Cr (chromium). The Fe particles were predominately (72%) in the coarse particle size. Particle concentrations reduced with distance from the railway line. PM10 concentrations at 120m from the railway were only 25% of that measured at 10m.

Image 3: Excessive temperatures in train brake assembly.

The German railway company, Deutsche Bahn AG, estimates the following emission factors from the contact line, braking and from the wheel/track interface:

Table 3 Non-exhaust emission factors for PM10 and PM2.5 from railways in Germany and France. PM2.5 in Germany is estimated as a fraction of 50% of PM10. Source: DEFRAa, 2019

Non-exhaust emission sources		**Emission factor (mg/km)**	
		PM10	**PM2.5**
Germany	Wear of braking system	6.0	3.0
	Wear of contact line	0.3	0.1
	Wear of wheel/track interface	18	9
France	Wear of braking system	5.0	2.3
	Wear of contact line	0.16	0.02
	Wear of wheel/track interface	3.4	1.0

An existing brake pad and disc combination provide a service life for the steel axle-mounted disc of between 800,000 and 1.1 million km. With an improvement in friction material, it is possible to improve the disc life to an estimated 2.57 million km, which means less wear and impacts from replacement.

2.3 Brake Particulate Matter Emission in Air Transport

Aircraft engines are just one of the many sources of pollution in the area of airports, but other sources are particularly dangerous at a local scale. Among them, the products of wear from tyres, brakes and runways. In addition to this, the strong air turbulence generated by aircraft leads to the resuspension of these pollutants in the air.

Image 4: Aircraft brake failure during landing.

An aircraft approach causes a significant effect on the quality of the air in the area adjacent to the airport. According to the study developed by Jasiński et al. (2016), at a distance of about 2 km from the aircraft touchdown point, the main symptom is a change in the concentration of particulate matter of diameter less than 100 nm (PM0.1 or UFP). These are the particulates that are most harmful to human health.

A single landing operation causes an increase in the value of particle number concentration by tens of times, and it is maintained for a period of at least 60 seconds.

In Conclusion

To conclude this section, we see that disc wear and particulate matter are intrinsically linked. Brake wear emissions have a significant contribution to particulate matter, which in turn exacerbates the conditions of air pollution, particularly in urban areas where there is increased usage of vehicles.

3. Product Life Cycle Environmental Impacts

Now we have looked at the immediate environmental impact of brake discs, let us now move on to discuss the longevity of this impact. This can be examined by looking at the life cycle of a brake disc, and the effect that this life cycle has on the environment in the long-term.

Brake discs and pads not only have a significant environmental impact due to wear but also during the product life cycle.

We've examined some of the significant environmental impacts that can occur during the life cycle. These include;

Mineral resources scarcity: *Assessment of consumption of natural resources, including their scarcity and the speed of their exploitation. The more the resource is considered as scarce and exploited, the more the value of the indicator increases, and the more the product contributes to the depletion of resources.*

Mineral resources scarcity impact category is expressed in kg of copper equivalent (kg Cu eq).

Freshwater eutrophication: *Freshwater eutrophication can be defined as nutrient enrichment of the aquatic environment. Eutrophication in inland waters as a result of human activities is one of the major factors that determine its ecological quality.*

On the European continent, it generally ranks higher in the severity of water pollution than the emission of toxic substances.

This category assesses substances (especially phosphates and nitrates) contributing to the proliferation of algae and aquatic species in the water. The respiration of these organisms, then their decomposition, cause a decrease in the dissolved oxygen content of the aquatic environment, disturbing the balance of the ecosystem, reducing animal and plant diversity, even causing it to disappear.

Freshwater eutrophication is expressed in kg of phosphorous equivalent (kg P eq).

Climate change: *Assessment of greenhouse gas emissions contributing to the greenhouse effect. The greenhouse effect causes changes in the Earth's climate, including an increase in average temperature.*

Climate change category is expressed in kg of carbon dioxide equivalent (kg CO_2 eq).

The Brake Disc Life Cycle

In Europe, there are approximately 238 million cars, which means there are 952 million brake discs and 1,904 million pads in existence. During the lifetime of a car, i.e. 240,000 km, motorists will expect to replace both brake discs and pads. The lifespan of the different parts depends on wear resistance. An average car will require 14 pads and 2.5 discs per disc brake in its lifespan.

Table 4 Disc brake parts required per brake during the car's lifetime and spare parts as replacements. Source: Gradin and Åström, 2020.

Disc brake part	Lifetime units required	Lifetime spare parts required
Pads	14	12
Discs	2.5	1.5

Considering the full life cycle of a passenger car brake disc during the vehicles lifetime, the environmental impact for the three categories is:

Table 5 Environmental results of a reference disc brake used during a car lifetime (240,000 km). Source: Gradin and Åström, 2020

Environmental impact category	Unit	Value per disc brake during the car lifetime
Mineral resources scarcity	kg Cu eq	1.53
Freshwater eutrophication	kg P eq	0.1
Climate change	kg CO_2 eq	90
Stratospheric ozone depletion	Kg CFC11 eq	0.000069
Ionizing radiation	kBq Co-60 eq	19.0
Ozone formation, human health	kg NOx eq	0.2
Fine particulate matter formation	kg $PM_{2.5}$ eq	0.9
Ozone formation, terrestrial ecosystems	kg NOx eq	0.2
Terrestrial acidification	kg SO_2 eq	0.6
Terrestrial ecotoxicity	kg 1.4-DBC e	41.8
Freshwater ecotoxicity	kg 1.4-DBC e	14.9
Marine ecotoxicity	kg 1.4-DBC e	88.9
Human carcinogenic toxicity	kg 1.4-DBC e	46.0
Human non-carcinogenic toxicity	kg 1.4-DBC e	36,532
Land use	m^2a crop eq	2.84
Fossil resource scarcity	kg oil eq	47.85
Water consumption	m^3	214.86

The brake considered in the study developed by Gradin and Åström (2020) weighs 7.058 kg, made up of 6.6 kg for the disc and 0.229 kg for each pad. The total amount of material consumed per 240,000 km is 19.7 kg, which, according to the results, is equivalent to consuming 1.53 kg of virgin copper (Cu).

It has to be considered that the studied brake is composed mainly of recycled material, with a low contribution to mineral resources scarcity.

Image 5: Brake disc waste.

It is interesting to note that the total greenhouse gas emissions for the lifespan of the braking system (in a car's lifetime) is 90 kg CO_2 eq. A vehicle will generate the same level of emissions in just a 508km journey in an average passenger car. (DEFRA, 2020b)

The fossil resource scarcity, related to fossil fuels consumption during the product life cycle, is 47.85 kg oil eq. This could be translated to non-renewable energy demand, of 2,195 MJ (2.18E-2 kg oil eq/MJ conversion factor).

Image 6: Environmental emissions.

The primary contributing impacts of reference disc brake materials and processes relate to;

- The cast iron they contain
- The manufacturing of the discs
- The manufacture of pads
- The materials in the pads friction mix, such as copper and brass.

The impact of the additional reference disc spare part also has a notable effect due to manufacturing and use of cast iron.

Some other impact categories were analysed by Gradin and Åström (2020), including 'Fine PM formation', 'terrestrial ecotoxicity', 'marine ecotoxicity' and 'human non-carcinogenic toxicity'.

For all these four categories, the life cycle impact was primarily linked to the brake wear emissions.

As the manufacturing stage is the most significant stage for impact categories related to climate change, water quality and material scarcity, the impact of this stage is analysed per one brake disc.

A car brake disc was studied by Andersson and Dettmann (2013), where the product was made of cast iron with 35% scrap and 65% pig iron, with nine variants of the product being considered. The weight of each product variant (finished product), raw material consumed and removal material during the product manufacturing (chips) is presented in the next table:

Table 6 Weight of each variant, expressed in kilograms. Source: Andersson and Dettmann, 2013.

Variant	Raw material	Finished product	Chips
1009091	12.60	8.54	4.06
1009092	9.50	6.46	3.04
1009093	11.08	7.4	3.68
1009094	12.60	8.54	4.06
1009095	12.19	8.77	3.42
1009096	9.90	7.06	2.84
1009098	9.5	6.46	3.04
1009099	11.08	7.4	3.68

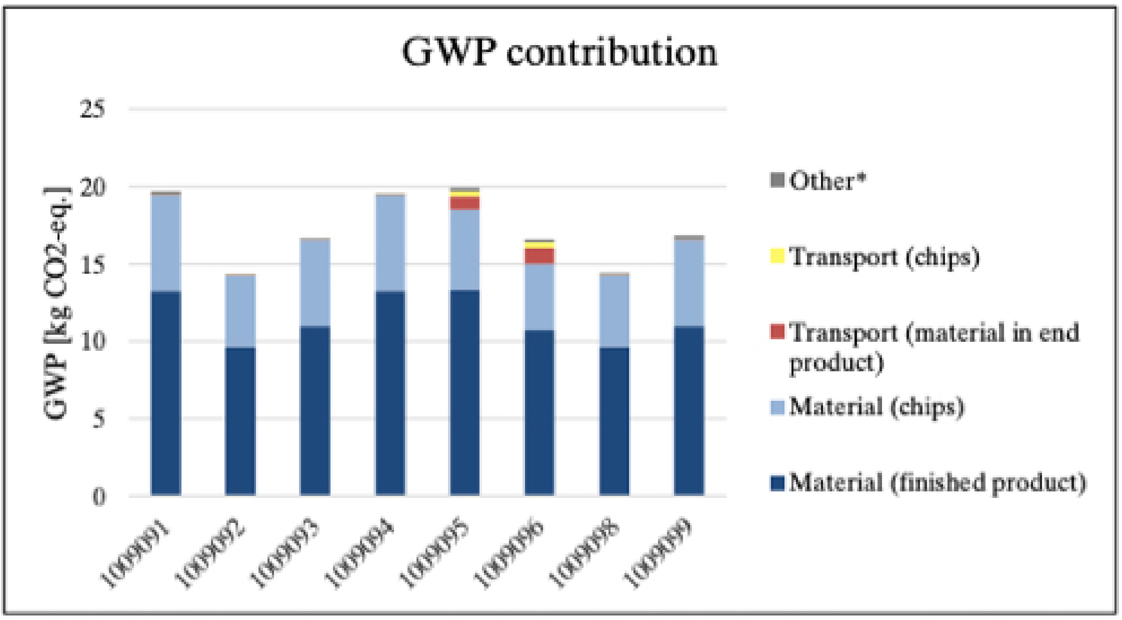
The environmental impact calculations resulted in an impact of between 14.4 and 19.9 kg CO_2 eq per brake disc, depending on the variant.

Table 7 Climate change (GWP), Acidification (AP) and Eutrophication (EP) results per brake disc. Source: Andersson and Dettmann, 2013.

Variant	GWP [kg CO_2-Eq]	AP [kg SO_2-Eq]	EP [kg NO_x-Eq]
1009091	19.7	0.0749	0.0563
1009092	14.4	0.0546	0.0411
1009093	16.7	0.0634	0.0477
1009094	19.6	0.0744	0.0559
1009095	19.9	0.0754	0.0597
1009096	16.6	0.0616	0.0501
1009098	14.4	0.0549	0.0413
1009099	16.8	0.0639	0.0481

The analysis showed that production of raw material (including both materials for finished products and removed material, i.e. chips) accounts for the major share of environmental impact. The main difference in impact can be attributed to different weights of the variants.

Figure 3 Carbon footprint of each disc brake variant and the contribution of raw material (used in the finished product or waste generated during the manufacturing process – chips), transport of raw material (used in the finished product or in the chips obtained as waste) and other processes. Source: Andersson and Dettmann, 2013.



*Other: Material (scrap), transports (scrap), electricity (finished product, scrap, factory), paint

So, to produce 200 disc brakes, assuming that an average disc weights 7 kg, this means 1,400 kg of steel would be consumed. Consequently, 3,465 kg CO_2eq would be emitted to produce them and 11,819 kWh of primary energy (electricity but also fuels, such as natural gas) would be consumed.

If instead of a 7 kg disc brake, we consider an 8.77 kg disc brake, the heaviest variant studied by Andersson and Dettmann (2013), which has a carbon footprint of 19.9 kg CO_2 eq, 200 discs would have a primary energy consumption of 14,808 kWh.

The carbon footprint of one 8.77 kg brake disc production would be equivalent to 69.8 miles when driving an average car, considering an emission factor of 0.28502 kg CO_2 eq per mile (DEFRA, 2019b).

4. Global Values

Now that we have discussed the immediate environmental impacts of brake discs for each sector, as well as their long term impacts throughout their life cycle, it becomes possible to imagine the global effects that they create.

The Effect of Passenger Vehicles

In Europe, there are approximately 238 million passenger cars, which means there are at least 952 million brake discs and 1,904 million pads in existence.

Each passenger car contains four brake discs and eight pads, which weighs approximately 30 kg in total. During the life span of a car, 240,000 km, ten discs will be required and 56 pads, which means that during the car life span almost 83 kg of cast iron will be consumed simply to perform the brake requirements. This doesn't take into account the other requirements of the vehicle.

In 2015, there were 947 million cars worldwide, which means that during their lifespan they will consume 78 million tons of brake material, mainly cast iron. The energy required to produce them is 662 million MWh, and they will emit 194 million tons of CO_2 eq, significantly contributing to climate change.

The Effect of Commercial Vehicles

Worldwide in 2015, 335 million **commercial vehicles**, such as lorries and vans, were circulating. Typically, commercial vehicles will need to replace their brake disc every 1.67 years, which means that every year 120 kg of steel is required per vehicle.

Consequently, the world's fleet consumes 40 millions of tons of steel annually. This comes with the subsequent energy demand of 390 million MWh, and greenhouse gas emissions, 119 million tons of CO_2 eq.

The Effect of Rail

In Europe, there are more than 585,000 **railway wagons** in use, that contain brake shoes. Due to abrasion of brakes, a wagon will require nine new brake shoes per year. This means consumption of 90 kg of cast iron annually.

For the wagon life span of 40 years, 3,600 kg of cast iron per wagon will be needed. If we extend this amount to all wagons in Europe, every year, 5 million brake shoes are replaced, which means 52,722 tons of cast iron consumed.

In terms of energy required to manufacture these new products, annually 445,095 MWh of energy will be consumed, which will have a carbon footprint of 130,488 t CO_2 eq.

The Effect of Aircraft

In 2018 the world's **aircraft** fleet totalled 25,830, with each aircraft containing, on average, 800 kg of braking sets.

An average aircraft wheel brake weighs approximately 100 kg and is made of steel or carbon fibre. If eight brake sets are needed per aircraft, the braking system of an average passenger or freight aircraft weighs 800 kg. This means that worldwide approximately 21,000 tonnes of aircraft brake is being used.

The average brake life span is 2,000 landings, which means that with the current number of flights globally performed, 21,000 tons of brakes will need to be replacing every 1.3 years.

Consequently, every year, 16,154 tons of material will be consumed to replace brake sets, which will have an energy demand during the manufacturing stage of between 126,868 MWh and 4,8 million MWh, depending on the brake material. The carbon footprint will be between 37,138 t CO_2 eq and 878,673 kg CO_2.

Table 8 Disc brake energy demand, carbon footprint and energy demand during the product manufacturing

Mean of transport	**Geographical scope**	**Temporal scope**	**Material consumption (tons)**	**Carbon footprint (tons CO_2 eq)**	**Energy demand (MWh)**
Cars	Worldwide: 947 million cars	Cars life span (240,000 km)	78,440,954	194,141,361	662,218,099
Commercial vehicles	Worldwide: 335 million lorries and vans	Yearly	40,433,432	119,172,780	390,421,843
Rail wagons	Europe: 585,000 wagons	Yearly	52,722	130,488	445,096
Aircrafts	Worldwide: 25,830 aircrafts	Yearly	16,154	37,138 (steel brake) – 878,673 (carbon brake)	126,868 (steel brake) – 4,837,598 (carbon brake)

Emissions are not confined to the area they are first produced in. Particulate matter is airbourne and therefore carried by weatherfronts across the globe. Within just a few days, these particles can cross continents effecting other nations populations.

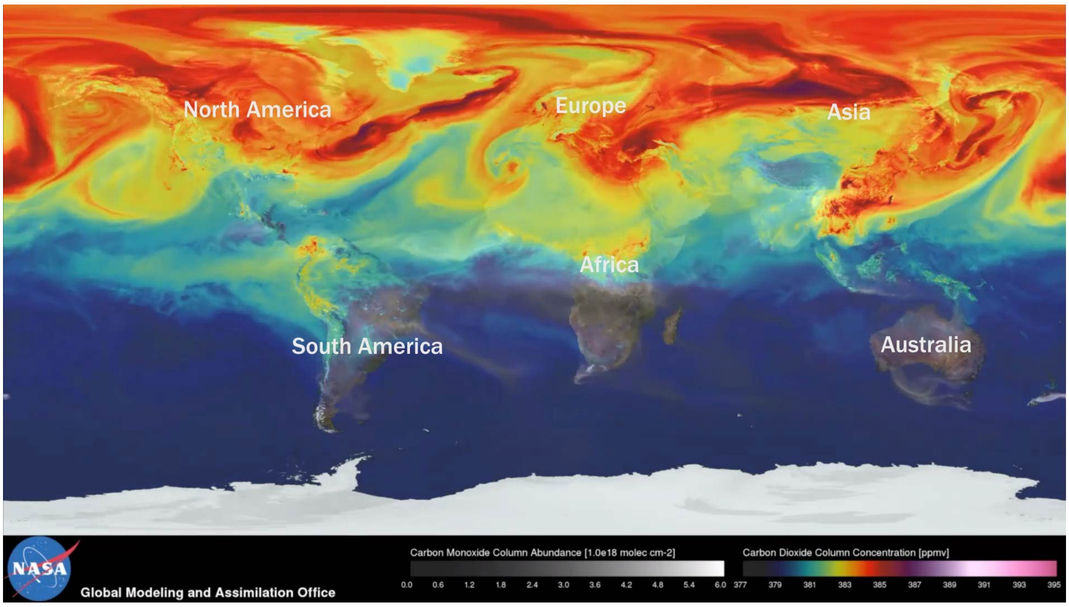


Image 7: NASA's monitoring of earths air pollution from space.

5. Health Impacts of Brake Wear and Particulate Matter

Now that this report has discussed and analysed the environmental impact of brake disc wear and particulate matter. It now becomes possible to examine the implications that this has on health.

Throughout this report, it has been made clear that the brake disc wear has a significant impact on the release of particulate matter into the atmosphere. Various studies have discussed the impacts of this particulate matter on the respiratory tract, which, in turn, causes health problems.

Image 8: Respiratory tract health impacts.

It is also important to note that particle size affects particle deposition. Therefore, these different particulate matter sizes have wide-ranging impacts on health in different areas of the body. For example, coarse particles are mainly deposited in the upper respiratory tract (nose and throat). In contrast, ultrafine particles penetrate deep into the lungs, thus posing hazards related to oxidative stress and inflammation.

PM2.5 are emitted directly from processes such as combustion and friction (such as through brake disc wear) and are also formed as a secondary pollutant. PM2.5 is one of the three major air pollutants that form part of the EC Ambient Air Quality Directive (2008/50/EC) and, as such, is an important measure when reporting on health impacts, particularly Coronavirus.

Conticini et al. (2020) used ambient ground-level air pollution data from air quality monitoring sites in Italy to provide "*evidence that people living in an area with high levels of pollutant are more prone to develop chronic respiratory conditions and suitable to any infective agent.*" This includes infective agents such as COVID-19.

PM2.5 has long been associated with negative effects on respiratory and cardiovascular health. They are also linked to adverse outcomes in neurodevelopment, cognitive function and other chronic diseases such as diabetes.

"Air pollution kills 7 million people a year and probably makes Covid-19 more deadly."

World Economic Forum 2020

This was further examined by the World Health Organization and World Economic Forum, which report that an estimated 7 million premature deaths globally are linked to ambient air pollution (AAP), mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children.

More specifically, AAP contributed to;

- 29% of all deaths and disease from lung cancer
- 17% from an acute lower respiratory infection
- 24% of all deaths from stroke,
- 25% of all deaths and disease from ischaemic heart disease
- 43% of all deaths and disease from chronic obstructive pulmonary disease (COPD).

The European Environment Agency's latest annual air quality report shows that most people living in Europe's cities are still exposed to levels of air pollution deemed harmful by the World Health Organization.

According to the report, fine particulate matter concentrations were responsible for an estimated 428,000 premature deaths in 41 European countries in 2014, of which around 399,000 were in the EU-28.

Hospital visit rates for known co-morbidities were calculated from NHS data from 2017 to 2018. These were split into cardiovascular and "other" co-morbidities to also examine known relationships of air pollutants on cardiovascular diseases. The conditions included were:

Alzheimer's disease

Alzheimer's disease is an irreversible, progressive brain disorder that slowly destroys memory and thinking skills and, eventually, the ability to carry out the simplest tasks. In most people with the disease - those with the late-onset type, symptoms first appear in their mid-60s.

Asthma

Asthma is a condition in which your airways narrow and swell and may produce extra mucus. This can make breathing difficult and trigger coughing, a whistling sound (wheezing) when you breathe out and shortness of breath.

Influenza and pneumonia

Influenza (flu) is a highly contagious viral infection that is one of the most severe illnesses of the winter season. Influenza is spread easily from person to person, usually when an infected person coughs or sneezes. Pneumonia is a serious infection or inflammation of the lungs.

Other acute respiratory infections

Acute respiratory infection is an infection that may interfere with normal breathing. It can affect just your upper respiratory system, which starts at your sinuses and ends at your vocal cords, or just your lower respiratory system, which begins at your vocal cords and ends at your lungs.

Bronchiectasis

Bronchiectasis is a disease in which there is the permanent enlargement of parts of the airways of the lung. Symptoms typically include a chronic cough with mucus production. Other symptoms include shortness of breath, coughing up blood, and chest pain.

Cancer

Cancer is a condition where cells in a specific part of the body grow and reproduce uncontrollably. The cancerous cells can invade and destroy surrounding healthy tissue, including organs. Cancer sometimes begins in one part of the body before spreading to other areas. This process is known as metastasis. Cancer is the second leading cause of death globally, accounting for an estimated 9.6 million deaths, or one in six deaths, in 2018.

Cardiovascular conditions (all: current or recent) -- ischaemic heart disease, angina, myocardial infarction; heart failure; stroke; and atrial fibrillation

Cardiovascular disease (CVD) is a general term for conditions affecting the heart or blood vessels. It's usually associated with a build-up of fatty deposits inside the arteries (atherosclerosis) and an increased risk of blood clots.

Chronic kidney disease including renal failure

The term "chronic kidney disease" means lasting damage to the kidneys that can get worse over time. If the damage is very bad, your kidneys may stop working. This is called kidney failure or end-stage renal disease (ESRD). If your kidneys fail, you will need dialysis or a transplant in order to live.

Chronic liver disease including liver failure

When you have cirrhosis, scar tissue slows the flow of blood through the liver. Over time, the liver can't work the way it should. In severe cases, the liver gets so badly damaged that it stops working. This is called liver failure.

Chronic obstructive pulmonary disease including respiratory failure

Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory lung disease that causes obstructed airflow from the lungs. Symptoms include breathing difficulty, cough, mucus (sputum) production and wheezing.

Dementia

Dementia is a syndrome in which there is deterioration in memory, thinking, behaviour and the ability to perform everyday activities. Although dementia mainly affects older people, it is not a normal part of ageing. Worldwide, around 50 million people have dementia, and there are nearly 10 million new cases every year.

Diabetes

Diabetes is a disease that occurs when your blood glucose, also called blood sugar, is too high. Blood glucose is your main source of energy and comes from the food you eat. Insulin, a hormone made by the pancreas, helps glucose from food get into your cells to be used for energy. Sometimes your body doesn't make enough - or any insulin or doesn't use insulin well.

Epilepsy

Epilepsy is a central nervous system (neurological) disorder in which brain activity becomes abnormal, causing seizures or periods of unusual behaviour, sensations, and sometimes loss of awareness. Anyone can develop epilepsy. Epilepsy affects both males and females of all races, ethnic backgrounds and ages.

Hypertension

Hypertension - or elevated blood pressure - is a serious medical condition that significantly increases the risks of heart, brain, kidney and other diseases.

HDP

Hypertensive disorders of pregnancy (HDP, including gestational hypertension, preeclampsia, and eclampsia) have a substantial public health impact. Maternal exposure to high levels of air pollution may trigger HDP.

Inflammatory bowel disease

Irritable bowel syndrome (IBS) is a common disorder that affects the large intestine. Signs and symptoms include cramping, abdominal pain, bloating, gas, and diarrhoea or constipation, or both.

Neurological conditions - motor neurone disease, Parkinson's disease and multiple sclerosis

Neurological conditions are disorders of the brain, spinal cord or nerves. They can have a range of causes including genetic factors, traumatic injury and infection. The causes of some of these conditions are still not well understood.

Osteoarthritis

Osteoarthritis is the most common form of arthritis, affecting millions of people worldwide. It occurs when the protective cartilage that cushions the ends of your bones wears down over time. Although osteoarthritis can damage any joint, the disorder most commonly affects joints in your hands, knees, hips and spine.

Osteoporosis

Osteoporosis is a health condition that weakens bones, making them fragile and more likely to break. It develops slowly over several years and is often only diagnosed when a fall or sudden impact causes a bone to break (fracture).

Rheumatoid arthritis

Rheumatoid arthritis is a long-term condition that causes pain, swelling and stiffness in the joints. The condition usually affects the hands, feet and wrists. There may be periods where symptoms become worse, known as flare-ups or flares.

Serious mental illness

Serious mental illness (SMI) is defined as a mental, behavioural, or emotional disorder resulting in serious functional impairment, which substantially interferes with or limits one or more major life activities. The burden of mental illnesses is particularly concentrated among those who experience disability due to SMI.

The above health conditions can affect the population's susceptibility to new threats such as Coronavirus but also SARS. For example, the Office for National Statistics (ONS) found that (without controlling for ethnicity), long-term exposure to fine particulate matter could increase the risk of contracting and dying from COVID-19 by up to 7%. (*United Kingdom's Office for National Statistics, August 13, 2020).*

Similarly, Wu et al. (2020) reported that "*long-term exposure to PM is positively associated with increased COVID-19 mortality".* Wu et al. specifically reported that a one µg m increase in average PM exposure would lead to an 8% increase in the -3 2.5 baseline death rate.

Particulate matter not only affects the health of the population, putting them at risk of contracting Coronavirus but also worryingly, particulate matter has also been seen to assist the spread of the virus itself.

For example, Setti et al. detected Coronavirus on particles of air pollution (*University of Bologna, PREPRINT posted April 24, 2020).* Setti et al. also found that higher levels of particle pollution could explain higher rates of infection in parts of northern Italy before a lockdown was imposed *(University of Bologna, PREPRINT posted April 17, 2020).*

Thus, it can be seen that particulate matter affects the environment not only through its air pollution. Research shows it also has a wide-ranging impact on various health conditions, including heart disease and respiratory illness.

These health impacts, in particular, affect the risks presented by Coronavirus, as these conditions not only increase the risks of contracting the virus but also the mortality rate. Moreover, while the research is new, it is increasingly suggestive that particulate matter has other impacts on the virus, such as affecting the way that it can be transported by air particles.

5.1 Health Impacts of Brake Wear and Particulate Matter on Wildlife

Animals, or wildlife, are also vulnerable to harm from air pollution. Pollutant issues of concern include acid rain, heavy metals, persistent organic pollutants (POPs) and other toxic substances.

When the water in the atmosphere mixes with certain chemicals, mild acidic compounds are formed. This acid rain can leach toxic aluminium from the soil, which at low levels can stress fish in lakes and streams or, at higher concentrations, kill them outright. Acid rain also weakens trees in forests and contributes to air pollution that can harm humans too.

Air pollution, particulate matter, and ground-level ozone, to mention a few, also likely affect wildlife health in similar ways to human health, including harming the lungs and cardiovascular systems.

An animal's vulnerability to air pollution is influenced by how it breathes - whether it uses lungs, gills or some other form of gas exchange, such as passive diffusion across the surface of the skin.

Image 9: Impact of pollution on fish.

"One-third of fish caught worldwide used as animal feed."

UN Food and Agricultural Organisation

Once consumed, many of these pollutants collect and are stored within the animal's tissues. As animals are eaten by other animals (and humans) along the food chain, these pollutants continue to gather and increase in concentration.

Image 10: Impact of pollution in the food chain.

Air pollutants can poison wildlife through the disruption of endocrine function, with other risks including organ injury, increased vulnerability to stresses and diseases, lower reproductive success and possible death.

It is also the case that many heavy metals, toxics, persistent organic pollutants (POPs) and other air pollutants affect wildlife by entering the food chain and damaging the supply and quality of their food.

This process is called bioaccumulation. Top-level predators such as bears and eagles, among many others, are particularly susceptible to the bioaccumulation of these types of air pollutants.

Changes in any species because of air pollution, or bioaccumulation can dramatically influence the abundance and health of dependent species.

For example, the loss of some species of fish because of higher levels of aluminium may allow insect populations to increase, which may benefit certain types of ducks that feed on insects. However, the same loss of fish could be detrimental to eagles, ospreys and many other animals that depend on fish as a source of food.

It is very difficult to fully understand and appreciate how far and in what ways such changes will affect other species throughout the ecosystem. However, experts agree that action is required to reduce the risks posed to all species with immediate effect.

6. Solution

Ogab® Sustainable Braking for Road, Rail and Aviation

Ogab® Sustainable Braking system offers increased safety levels, optimised brake performance and significantly reduces the damaging environmental impact caused during the product life cycle of disc brakes and pads.

By optimising the operational brake disc temperature and preventing excessive heat accumulation, maximum efficiency is maintained for the highest standard in performance and safety. This means shorter stopping distances and an extended lifespan on all brake discs for road vehicles, trains and aircraft.

This preventative method of keeping the disc at optimum temperature prolongs the life of the brake disc through eliminating product degradation due to friction and extreme heat.

This prolonged lifespan results in significantly reducing the damaging environmental impact caused by excessive manufacturing demand of both discs and pads, as well as the endless struggle that follows when the discs need to be recycled.

The harmful emissions that are released due to the burn up of the pads at high braking temperatures are also reduced. This reduction in particle emissions is beneficial for both the health of the environment and all members of society itself. We have detailed our research below to help communicate this solution that applies across the modern transport sector.

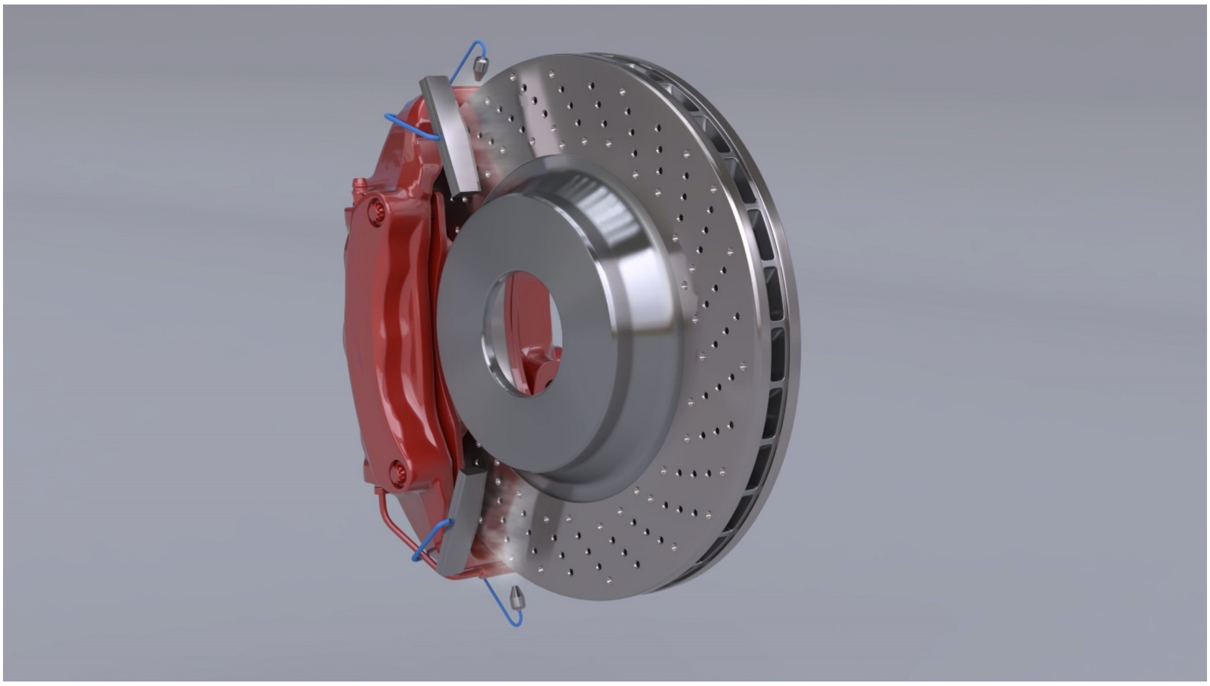


Image 11: Example of brake cooling technology.

6.1 Sustainable Braking for Road Vehicles

The action of braking generates massive amounts of heat as the kinetic energy is converted into heat by creating induced friction. Since brake components have a relatively narrow temperature window within which they can operate effectively; their performance degrades drastically when they exceed their maximum temperature rating.

The majority of brake discs (brake rotors) are designed so that they can dissipate heat passively and via convection through several holes and slots fabricated within the solid body of the disc. However, in vehicles with a wheel well (such as cars) and vehicles where the brake rotors are disposed within the barrel of the wheel, the air around the brake discs is turbulent. This means efficient cooling cannot be achieved (for instance, when compared to the speed of the vehicle) as the air velocity is not considerably high.

A lack of efficient cooling causes a heat build-up around the brake components and diminishes their ability to shed that heat. In contrast, by applying air from a high-pressure source, this will allow the brakes to shed heat at a faster rate and dramatically lower the average disc solid temperature.

Ogab® Sustainable Braking utilises patented Active Flow Control Technology that is powered only by energy that would be otherwise be lost.

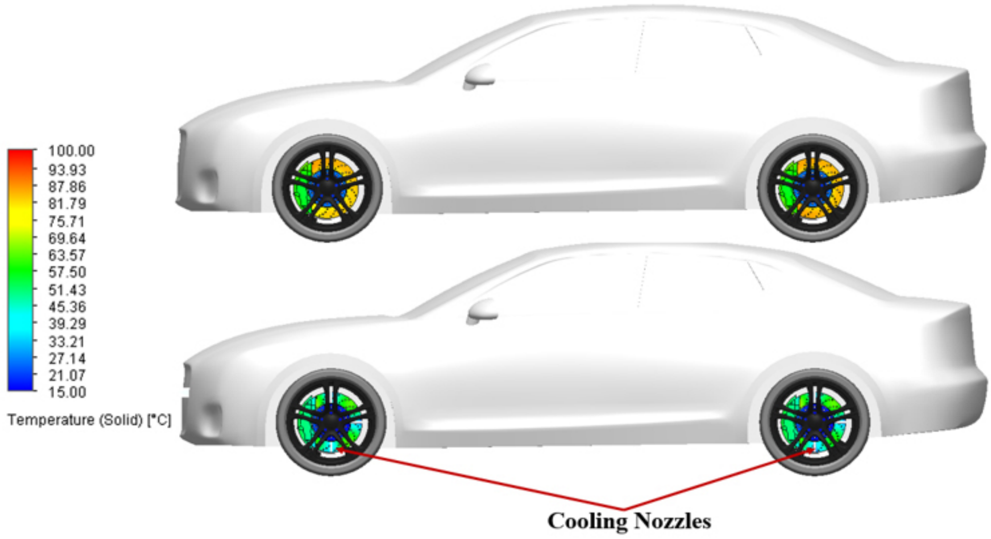
We have completed CFD simulation tests on an Audi A4 car to demonstrate the benefits of the Ogab® patented active flow cooling technology. The simulations were conducted for two different scenarios; without brake disc cooling and with brake disc cooling. Two common brake disc materials; carbon-carbon composite and grey cast iron were also investigated.

The vehicle has a cruising speed of 70 miles per hour which stops in 4.31 seconds. The transient simulation was run for 30 seconds in which for the first 4.31 seconds the car reduces its speed linearly from 70 miles per hour to zero and then remains stationary up to t=30s. All the generated heat as a consequence of kinetic energy conversion to thermal energy was released during the first 4.31 seconds of the simulation.

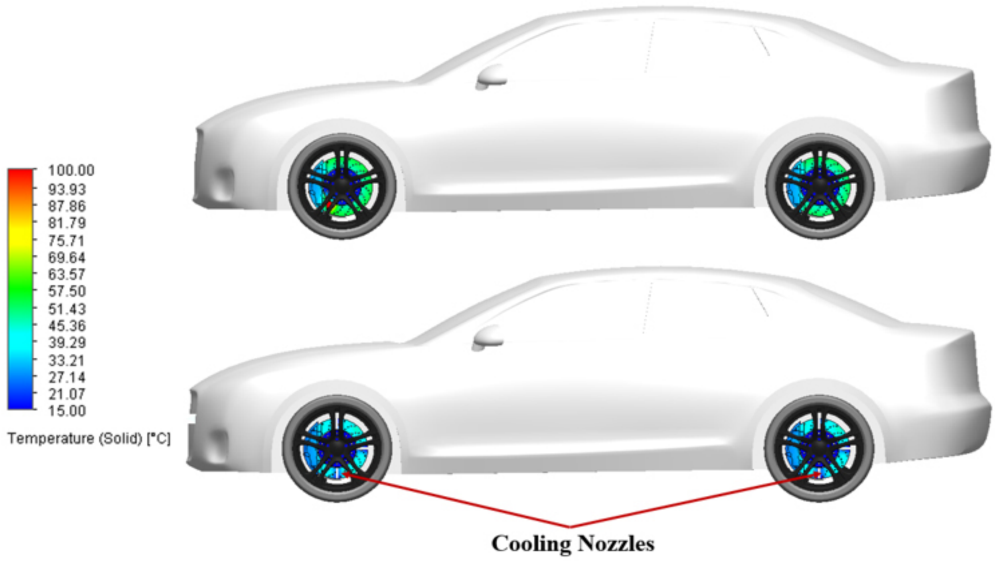
With brake disc cooling, the Ogab® patented active flow cooling technology was implemented within the brake disc assembly and remained operative for all 30 seconds of simulation.
It was shown that the proposed cooling technology was effective in reducing the rotating disc average temperature. The results are depicted in figure 4 below.

It was possible to reduce the overall disc average volume temperature by 29.42% for the carbon-carbon material and by 16.5% for the grey cast iron material when utilising the Ogab® cooling technology compared to without cooling.

Figure 4 Results of brake disc cooling. Source: Ogab®, 2020.



Disc and pad solid temperature contours for carbon-carbon material (top) without cooling nozzles (bottom) with cooling nozzles at t=30s



Disc and pad solid temperature contours for grey cast iron material (top) without cooling nozzles (bottom) with cooling nozzles at t=30s

Offering innovation for a brighter future, Ogab® Sustainable Braking gives the solution to a problem that affects us all in our day to day lives.

The system is not just unique to road vehicles such as the Audi A4 as it can also apply to both the rail and aviation industry also.

6.2 Sustainable Braking for Rail

On most trains, each of the main wheels is equipped with a brake unit. In the railway industry, the performance and efficiency of the brake systems are crucial for the safety of passengers and those on the ground. Due to the very high weight of trains and low friction between the wheels and rails, the design of the brake system is of paramount importance.

All trains utilise brake discs that operate on induced friction between rotating and stationary discs inside the brake. Disc brakes consist of two main components; the rotor and stator. The rotating disc (rotor) is keyed to the wheel rim and rotates with the wheel while the stator (brake lining) is attached to the train's chassis. When the driver activates the air brakes, the brake lining squeezes to the rotor and creates friction which reduces speed.

Train brakes are often made of grey cast iron due to its desirable mechanical properties. The main function of brakes is to convert the kinetic energy of train into heat/thermal energy by creating friction. Therefore, a massive amount of heat is generated due to the enormous weight and velocity of trains. Hence, the brake system components need to withstand a very harsh environment.

Since brake linings (stators or brake pads) are wearable, activating brakes causes significant material consumption on pads. Consequently, environmentally harmful debris is released to the surroundings by each brake activation (which also increases the maintenance cost).

Ogab®'s research programme carried out simulation tests on a Class 220 Voyager Train commonly used on railways in the United Kingdom.

In the test, our novel technology is developed and deployed to reduce the brake disc temperature during the function of braking and for three minutes afterwards.

By successful demonstration of such unique technology, it is possible to increase the maintenance requirement period and substantially extend the lifetime of the braking system's consumable material (i.e. wearable brake pads) and reduce their adverse environmental effects. In addition, it can significantly increase the safety of the railway sector.

Similar to the road application, we have completed CFD simulations on the aforementioned train class to highlight the benefits of the unique Ogab® system. The simulations were performed for two scenarios; without brake cooling and with brake cooling.

For the simulation test case with the proposed brake cooling technology, the system was activated onset of the braking function (brakes engaged). It remains active for the braking period (i.e. for 62.5 seconds), and then it remains operative for an additional 177.5 seconds (i.e. to t=240s).

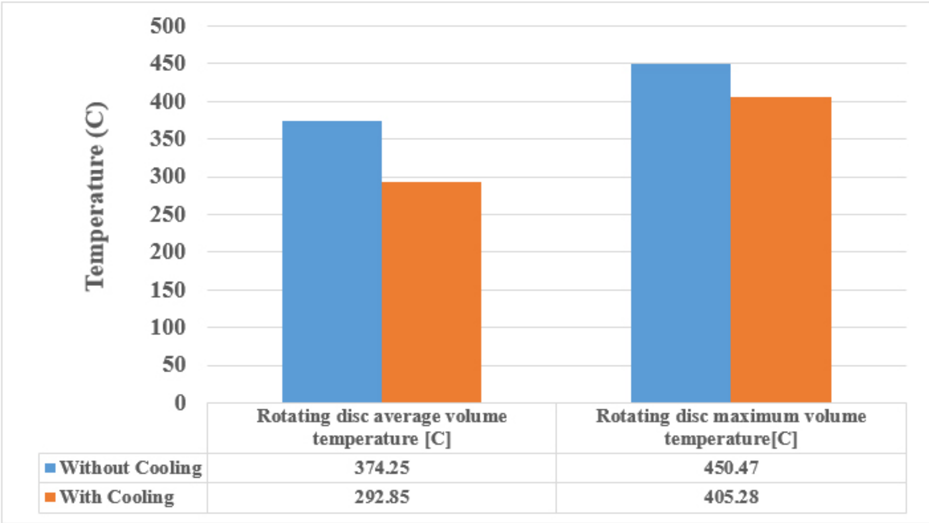
All of the generated heat as a consequence of kinetic energy conversion to thermal energy was released during the first 62.5 seconds (i.e. from t=0s to t=62.5s). From t=62.5s till t=240s the brakes were released, but the cooling system remained operative.

The brake disc average and maximum volume temperature for the case without cooling and the case with cooling were compared at two time moments as t=62.5s (end of the braking function) and t=240s (end of simulation).

As evident from the figure 5 below, deploying the cooling technology proved to be effective as it reduces the rotating disc average volume temperature from 374.25C to 292.85C (**21.75%**

improvement). In comparison, the maximum disc volume temperature reduces from 450.47C to 405.28C (**10.03%** improvement) during the 62.5 seconds of braking.

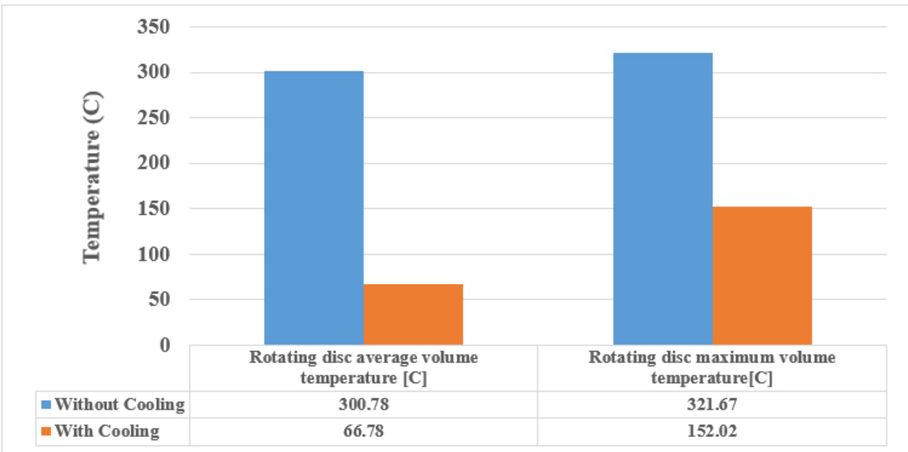
Figure 5 Comparison of temperatures with and without brake disc cooling. Source: Ogab®, 2020.



Comparison of temperature between the case without cooling and case with cooling at t=62.5s

The suggested cooling technology provided excellent results after 240 seconds as highlighted. With such technology, it was possible to reduce the brake disc average volume temperature from 300.78C to 66.78C (**77.79%** improvement) while the maximum disc volume temperature reduces from 321.67C to 152.02C (**52.74%** improvement).

Figure 6 Comparison of temperature between the case with and without cooling at t=240s Source: Ogab®, 2020.



Comparison of the temperature between the case without cooling and with cooling at t=240s

It is evident from these figures that, the cooling was beneficial in reducing the disc temperature at various time steps, with the temperature of the whole disc assembly being very low with the implementation of the cooling technology active for 240 seconds.

Figure 7 Evolution of brake disc volume temperature. Source: Ogab®, 2020.

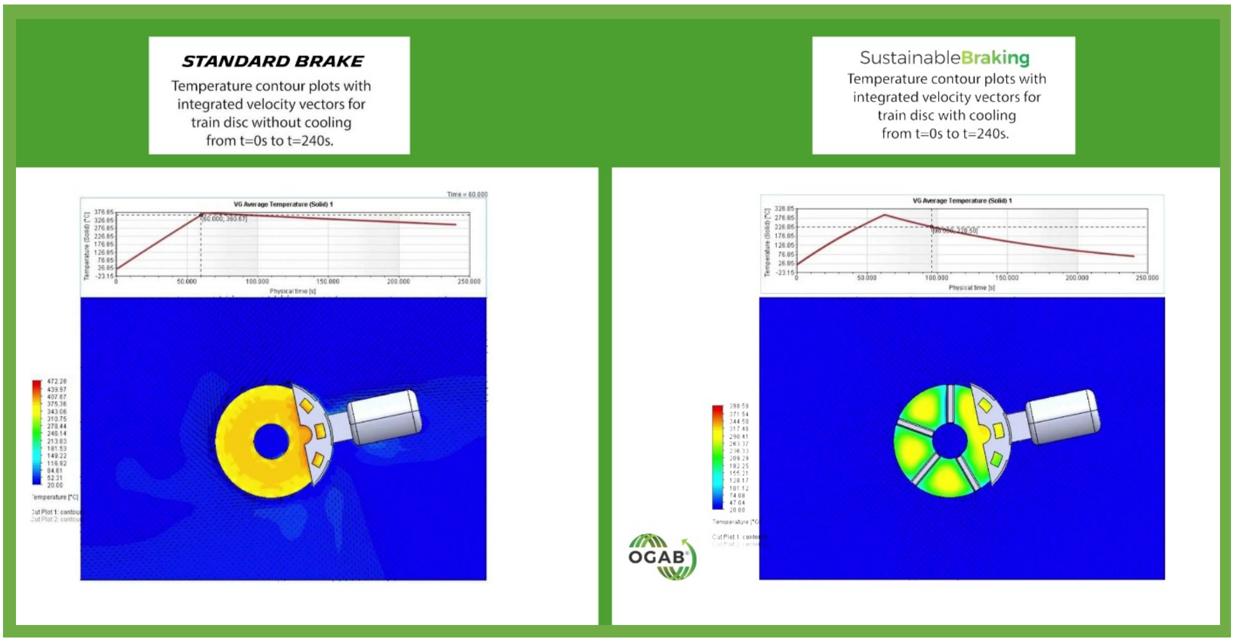


Figure 7, shown above, presents the evolution of the brake disc average volume temperature for the conventional passive cooling, and the Ogab® patented active cooling system during the whole period of simulation.

It is evident that both the escalation rate of temperature from t=0s to t=62.5s and the reduction rate have been substantially improved using the proposed Ogab® technology. It was demonstrated that with the utilisation of such novel technique that it is possible to reduce the disc average volume temperature by the maximum value of 21.75% after 62.5 seconds and by 77.79% after 240 seconds.

6.3 Sustainable Braking for Aviation

Modern aircraft typically use brakes that can be made up of a single, dual or multiple brake disc set up and even segmented rotor brakes depending on the type of aircraft.

The disc rotates with the turning wheel assembly, and stationary callipers act against the rotation of the disc by causing friction against the disc when brakes are applied.

At the significant speeds aircraft lands at, this transfer of kinetic energy to heat energy in order to slow the aircraft can result in very substantial heat build-up that can lead to brake failure at the extremities, causing pilots to lose control.

Abused brakes can also catch fire in some cases and can even cause tyre deflation/tyre burst, posing significant risks to passengers as well as causing costly damages.

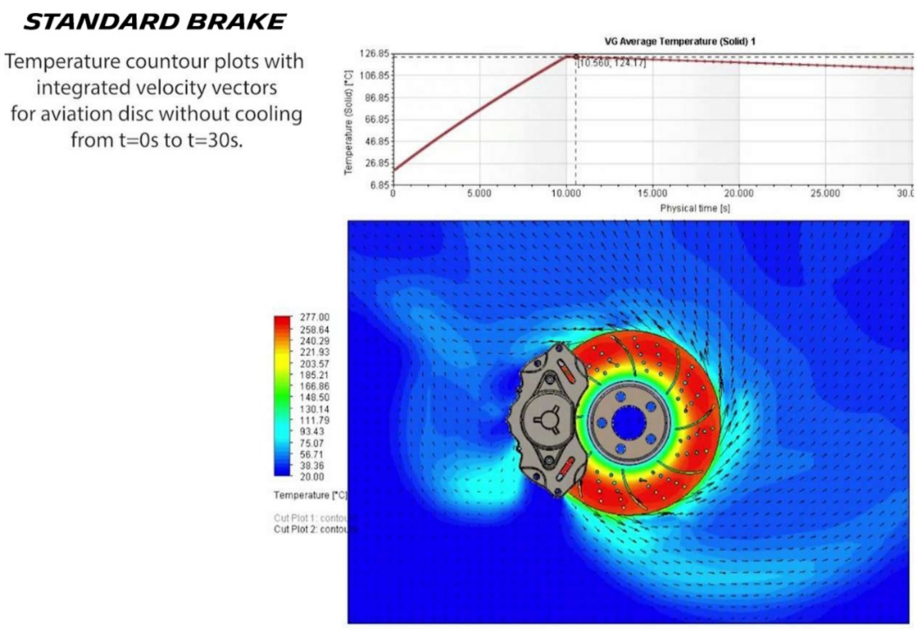
Brake overheating also causes major delays in the exchange window of flights whilst aircraft brakes are cooled between passenger flights. These delays can increase the cost of flights when there are fewer flights per day, and consequently increase the cost of flight tickets for the consumer.

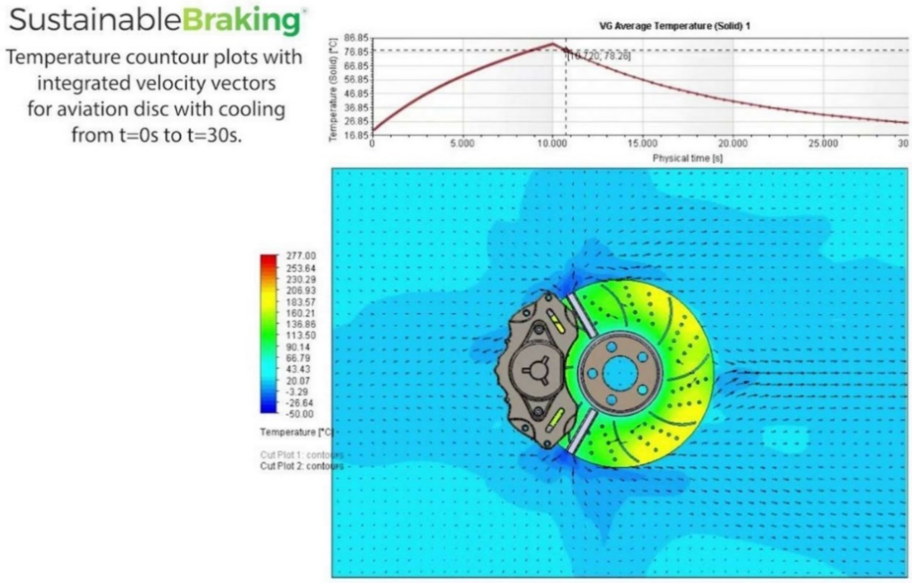
In our studies at Ogab®, we have experimented with the light aeroplane 'Beechcraft Bonanza' to demonstrate the effectiveness of our proposed brake cooling systems.

In the CFD simulations, Ogab® experimented the same scenarios as the road and rail applications to highlight the usefulness of the Ogab® Sustainable Braking against the conventional cooling systems.

Ogab® technology was implemented on the aforementioned aircraft for 30 seconds in which 10 seconds were the braking and cooling, and the additional 20 seconds was cooling only. The results were quite promising, as shown by figure 8, below.

Figure 8 Aircraft braking temperatures. Source: Ogab®, 2020.

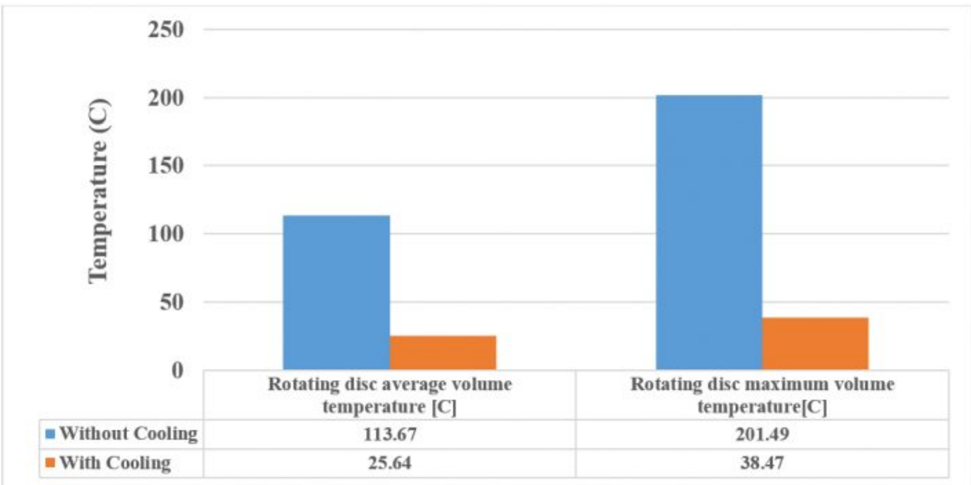




Deploying our cooling technology proved to be effective as it reduces the rotating disc average volume temperature from 124.54C to 82.85 (33.5% improvement) while the maximum disc volume temperature reduces from 277.3C to 208.5C (24.8% improvement) during the 10 seconds of braking.

The suggested cooling technology provided excellent results after 30 seconds, as highlighted by the results in figure 9 below. With such technology, it was possible to reduce the brake disc average volume temperature from 113.67C to 25.64C (77.44% improvement) while the maximum disc volume temperature reduces from 201.5C to 38.47C (80.89% improvement).

Figure 9 Comparison of brake disc cooling in aviation. Source: Ogab®, 2020.



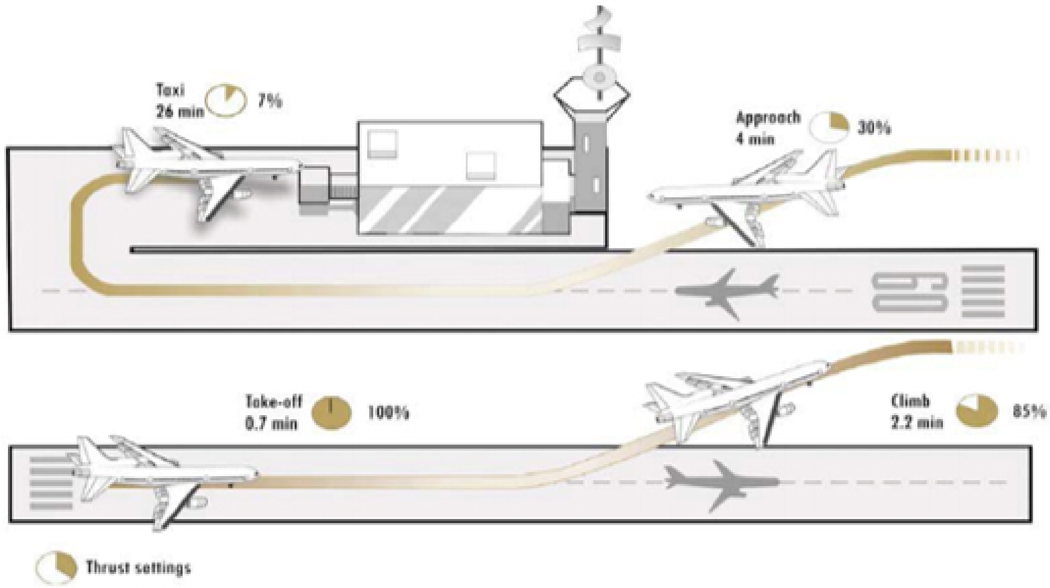
Comparison of the temperature between the case without cooling and case with cooling at t=30s

By limiting the temperature ranges to 70 degrees less than the original maximum without our cooling nozzles, we can significantly reduce the safety concerns involved in aircraft braking.

The efficiency of braking is also much improved. The aircraft can reach taxi speeds much quicker and safer. The turnaround of flights can also be majorly improved since the brakes can be continued to be cooled throughout braking and taxi speeds before the aircraft even reaches its dock, allowing atmospheric temperatures to be achieved much quicker.

The efficiency of braking is much improved. The aircraft can also reach taxi speeds quickly and safely.

Figure 10 Demonstration of time-saving capabilities with aircraft brake cooling. Source: Ogab®, 2020.



Currently, in commercial passenger aircraft, an external cooling system is utilised as depicted below.

Image 12: Demonstration of an aircraft external cooling system.

Such systems consist of bulky equipment including an extraction fan and piping that are externally attached to the rim of each wheel to remove the hot air that is generated as a consequence of the braking action.

This procedure is carried out after the aircraft reaches the terminal and is in a stationary mode. Ground services spend a significant amount of time cooling down the brakes, which slows down the flight frequency of each individual aeroplane.

Some conventional cooling systems claim that they can reduce the brake disc temperature by 200C in 30 minutes. However, if brake cooling can be done during the braking period and on the runway prior to a complete stop and reaching the terminal. This means it's possible to save a significant amount of time on the ground. Consequently, you can eliminate all the efforts related to aircraft brake cooling and the required workforce.

Our results show that it is possible to cool brakes in light aircraft to ambient temperatures in seconds and large airliners in minutes, not hours.

It was shown that the proposed cooling technology was beneficial in reducing the brake disc temperature for a single brake disc and pad assembly on the runway within a few seconds. Our study indicates that it is feasible to effortlessly, securely and internally reduce the brake system temperature in a much shorter period of time than the conventional systems.

There is no need for external equipment, and the system can be initiated remotely by the pilot. This technology can be easily extended to the dual or multiple brake disc systems suitable for commercial passenger aircraft.

Upon deploying such technology, it is possible to remove all the necessary actions for the brake cooling during the plane preparation period and hence increase the flight frequency of an airliner and reduce the service and maintenance costs.

7. Conclusion and Recommendation

This report has first examined the relationship between brake disc wear and particulate matter. It has utilised compelling statistical data to give evidence of the actual impact on brake disc wear through particulate matter in the three main modes of transport: road, rail and aviation.

Having examined this relationship, the life cycle of brake discs has then been discussed to assess how the particulate matter, air pollution and other forms of pollution continues. This is not just through the life of a brake disc but also through the ongoing and prolonged life of the vehicle on which they were used. As such, the production and use of brake discs mean that pollution continues even after the first brake disc is used as they continue to be replaced.

Finally, this report discussed the impacts of particulate matter and ambient air pollution on the health of the population.

It is therefore clear to see that brake discs have a significant impact on the production of particulate matter and other forms of pollution throughout a vehicle's life. This impact is not limited to the road network but rather the whole transport network.

This environmental impact, by extension, comes to affect world health in significant and life-changing ways. It is therefore crucial not just for the sake of the environment, but also for the health of the global population that we continue to reduce our carbon footprint and pollution, especially air pollution and particulate matter.

One way in which we can reduce particulate matter and air pollution is through investment and research on environmentally friendly technologies to reduce brake wear and, consequently, the release of harmful debris.

One effective solution is to prevent brake disc temperature escalation where it releases harmful particulate matter at high temperatures. The developed technology discussed in this report from Ogab® helps to meet this requirement across the transport sector to offer a solution.

It should be noted that the proposed cooling technology discussed in the report was deployed to an existing brake system design in each case. Therefore, its performance was limited by the nature of the current brake systems configuration.

By considering the proposed cooling technology (which was proved to be very effective) during the design process of new brake system assemblies, it can enhance the cooling performance even further and provide more integrated configurations of the brake system (i.e. embedded cooling within the brake system).

In addition to this, the current braking technology relies heavily on aerodynamics to cool the brakes after friction occurs and for the heat to then dissipate during motion. As Ogab® technology does not rely on aerodynamics to cool the brakes, it has a complete, separate system (that injects air) which allows the proposed brake cooling technology to be integrated within a more advanced system.

Such a system encloses the brake disc and pads as well as the cooling technology within a sealed compartment in which the particulate matter and environmentally harmful debris that are released as a result of the braking function can be effectively captured. Afterwards, in a proper location (for example in a petrol station or vehicle dealership facilities) such debris can be discharged safely from the confined space in the vehicle into a specially designed vessel for after treatment to alleviate their adverse environmental effects. With such a methodology, the harmful impact of braking can be minimised by controlling the release of particulate matter.

In light of the data provided in this report, it is highly recommended that the information relating to the harmful impacts of brake wear on human health and the global ecosystem as a whole needs to be recognised.

This includes a recommendation to review the policy that has been approved by UK parliament (and has now become law) regarding the target of bringing all greenhouse emissions to net-zero by 2050.

Considering the fact that in urban environments, brake wear can contribute up to 55% by mass to total non-exhaust traffic-related PM10 emissions and up to 21% by mass to total traffic-related PM10 emissions, this is clearly not possible based on current technology.

Ogab®, of course, supports this target of net-zero emissions. However, due to current misinformation around electric vehicle emissions, transparency from manufacturers and governments is vital. There should be evidence when providing data on brake wear. Currently, this has not been considered within the frame of this law.

This recognition includes acknowledgement and action from government bodies, the transport industry and the wider global population. The technology described in the report offers a highly suitable solution to address the discussed issues in a sustainable manner where no energy is consumed for running the system while reducing the brake wear.

It is recommended that it should be implemented within the matrix of solutions for combating the harmful impacts of brake wear on human health and the global ecosystem.

Ogab® will continue to develop our innovative sustainable braking technology to support the reduction of particulate matter and pollution for a better and brighter future.

"Together, we can create a better future; if we make the right decisions at this critical moment, we can safeguard our planets ecosystems, its extraordinary biodiversity and all its inhabitants. What happens next is up to every one of us."

Sir David Attenborough

Extinction: The Facts - BBC 2020

Report presented by Ogab Limited – 2020

For further information contact info@ogab.co.uk

To learn more about our Sustainable Braking technology visit www.ogab.co.uk

8. Glossary of Terms

Environmental impact category	Unit	Description
Climate change	kg CO_2 eq	An increased atmospheric concentration of greenhouse gases will increase the radiative forcing capacity leading to an increase in the global mean temperature (°C). Increased temperature ultimately results in damage to human health and ecosystems.
Stratospheric ozone depletion	Kg CFC11 eq	Emissions of Ozone Depleting Substances ultimately lead to damage to human health because of the resultant increase in UVB radiation. Chemicals that deplete ozone are relatively persistent and have chlorine or bromine groups in their molecules that interact with ozone (mainly) in the stratosphere. This increased radiation negatively affects human health, thus increasing the incidence of skin cancer and cataracts.
Ionising radiation	kBq Co-60 eq	Anthropogenic emissions of radionuclides are generated in the nuclear fuel cycle (mining, processing and waste disposal), as well as during other human activities, such as the burning of coal and the extraction of phosphate rock. Exposure to the ionising radiation caused by these radionuclides can lead to damaged DNA molecules and thus affect human health.
Ozone formation, human health	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non-Methane Volatile Organic Compounds (NMVOCs). This formation process is more intense in summer. Ozone is a health hazard to humans because it can inflame airways and damage the lungs.
Fine particulate matter formation	kg $PM_{2.5}$ eq	Air pollution that causes primary and secondary aerosols in the atmosphere can have a substantial negative impact on human health, affecting the upper part of the airways and lungs when inhaled.
Ozone formation, terrestrial ecosystems	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non-Methane Volatile Organic Compounds (NMVOCs). Ozone can have a negative impact on vegetation, including a reduction of growth and seed production, an acceleration of leaf senescence and a reduced ability to withstand stressors.
Terrestrial acidification	kg SO_2 eq	Atmospheric deposition of inorganic substances, such as sulphates, nitrates and phosphates, cause a change in acidity in the soil. This change in acidity can affect the plant species living in the soil, causing them to disappear
Freshwater eutrophication	kg P eq	Freshwater eutrophication occurs due to the discharge of nutrients into the soil or freshwater bodies and the subsequent rise in nutrient levels, i.e. phosphorus and nitrogen. Environmental impacts related to freshwater eutrophication are numerous. They follow a sequence of ecological impacts offset by increasing nutrient emissions into freshwater, thereby increasing nutrient uptake by autotrophic organisms such as cyanobacteria and algae, and heterotrophic species such as fish and invertebrates. This ultimately leads to a relative loss of species.
Terrestrial ecotoxicity	kg 1.4-DBC e	Human toxicity and ecotoxicity account for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. This can result in affected species and disease incidences, leading finally to damage to ecosystems and human health.
Freshwater ecotoxicity	kg 1.4-DBC e	
Marine ecotoxicity	kg 1.4-DBC e	
Human carcinogenic toxicity	kg 1.4-DBC e	
Human non-carcinogenic toxicity	kg 1.4-DBC e	
Land use	m^2a crop eq	Land use includes the direct, local impact of land use on terrestrial species via change of land cover and the actual use of the new land. Change of land cover directly affects the original habitat and the original species composition accordingly.
Mineral resources scarcity	kg Cu eq	Assessment of consumption of natural resources (distinguished in two indicators depending on whether the resources are energy or non-energy) including a weighting of these resources according to their scarcity and the speed of their exploitation. The more the resource is considered as scarce and
Fossil resource scarcity	kg oil eq	

		exploited, the more the value of the indicator increases, and the more the product contributes to the depletion of resources.
Water consumption	m^3	Water consumption is the use of water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds or disposed into the sea. Water that has been consumed is thus not available anymore in the watershed of origin for humans nor for ecosystems
Cumulative energy demand	MJ	The Cumulative Energy Demand represents the direct and indirect energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials.

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