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Bionic design of brake pad dust collector inspired by Sea shell

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Abstract

This study presents an innovative dust collector design that is based on natural principles. Specifically, the paper draws inspiration from the complex architecture of seashells and honeycombs. The purpose of the cover is to efficiently gather particulate matter (PM) particles that are produced when cars apply their brakes. This will help to mitigate issues with air pollution and environmental contamination. The dust collector has a unique design with tiny internal chambers that resemble the elaborate chambers seen in seashells. These compartments are purposefully made to effectively capture and hold PM particles released during braking. The filtering, impaction, and interception techniques used in their construction are modeled by biological systems found in nature. Moreover, the dust collector's design is built to seamlessly integrate with cars' current braking systems. Its modular construction makes installation and retrofitting simple and guarantees compatibility with a variety of car types and setups. The suggested dust collector provides an eco-friendly and sustainable means of reducing brake-generated particulate matter emissions by utilizing the concepts of bionics and biomimicry. In vehicle applications, this creative design offers a viable means of lowering air pollution and fostering healthier, cleaner surroundings.

Keywords: Particulate matter (PM), Brake pad, Dust collector, Bionic design, Sea shell, Honeycomb, Recycling.

1. Introduction

Forthcoming issues regarding pollution need modifications in existing systems which are already in usage. According to the current scenario the major pollution factor is the automobile sector. Lots of improvements have been implemented in the sector of exhaust emission purification. There are also some other sources of pollutants in automobiles which produce unwanted particles, like tire and brake pad wear material exhales in air, evaporative emission, fluid leaks, road dust etc. This document focuses mainly on the particulate Matter generated by brake pad wear.

The particulate matter generated from brake pad wear can affect the human body harshly as well as the environment. There will be an increase in chances of getting respiratory issues like asthma, bronchitis by inhaling this particulate matter. Some kind of neurological and heart disease may occur due to this particulate matter and high risk of cancer in the human body. On the other hand, environmental issues like climate change, air pollution, smog formation and a wicked effect on vegetation occurred.

Worldwide, there is rising concern about air quality. The World Health Organization's (WHO) 2005 Air Quality Guidelines examine the impact of air pollution on human health and set criteria for levels of pollution that are detrimental to human health. The PM2.5 and PM10 thresholds are 10µg/m3 annual mean 25 µg/m3 24-h mean and 20µg/m3 annual mean 50 µg/m3 24-h mean respectively [16].

Earlier research and development on this subject lead to alteration in brake pad material from asbestos to organic, development in recycling procedures of brake pads, introduction of regenerative braking system in EV to reduce amount of friction braking and introduction of some electronic control systems on brakes to reduce direct exhales of PM to the environment.

Some recent developments are also there in which active vacuum systems are used to trap PM particles generated from the braking system. This kind of system is working with external power from the battery or engine, which directly affects the power of the vehicle.

To avoid the dependancy for external power from battery or engine, there is a scope to find a sustainable way to trap the PM particles. Taking the inspiration from nature, a design has been made inspired from sea-shell to passively (no additional power input is required to function) collect the PM particles emitted from the brake pads while braking.

2. Area of Improvement

For making a collection system for PM particles generated from brake pads the deep analysis of path required on which exhaled PM particles travel. According to the examination of modern Light motor vehicle braking systems the route of these particles is roughly on the periphery of the disc [5].

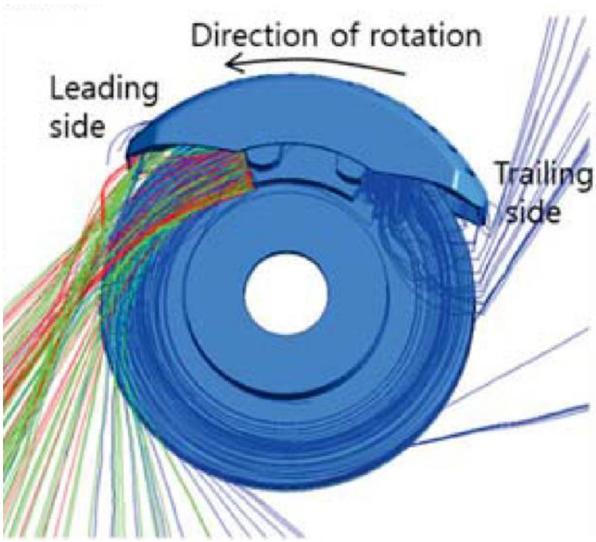

Fig. 1: Path of PM Particle during braking Application [5]

The behavior of PM particles during braking operation shows in the figure. The average PM-10 emission factor of light motor vehicles was determined to be 13.6 mg/km/vehicle [3]. This amount of emission is only from passenger cars. If consideration extends towards heavy vehicles and agricultural usage the digit may be increased by fantastic numbers.

To collect the maximum amount of splashed PM particles from the peripheral area of the disc, a device is required which works as a dust collector and easily accommodates after brake caliper assembly.

The required cover has features to trap the small PM particles, withstand high temperature, corrosion resistant, compact, lightweight and enough space to store half-life material of brake pad. To fulfill the feature requirement only technological information is not enough. Thus, bionics is taken into consideration as an inspiration.

3. Inspiration from Bionics

Most of the inventions are done with two main things first is human need and secondly from inspiration from nature. Here to fulfill the requirement needs particularly inspiration taken from sea creatures.

The thought behind this idea is the working environment. The task is to collect very small particles which somewhat look like sea soil.

In this unique design of brake dust collector, the shape is inspired and designed according to the sea Nautilus Shell.

Fig. 2: Sectional and exterior view of the sea Nautilus Shell [17][18]

This pattern is known as an equiangular spiral and also considered as the golden spiral. The golden spiral is a geometric way to represent the Fibonacci series and is represented in nature [19].

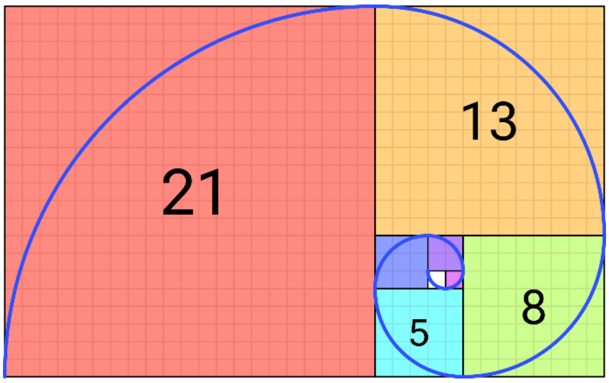

Fig. 3: The Fibonacci spiral [19]

The same concept can be used with the design of brake dust collector cover. There are the number of things for choosing this shell.

- It has more surface contact area.
- It has more compartments for storage which is made as a one-way kind of con.
- The complex texture of the surface is also useful for particle traps.
- Shape of the opening is bigger which can provide more frontal trap area for PM collection.

The involute profile of fin arrangement inside these shells are very creative on its own. This profile is useful to guide the upcoming flow of the PM particles. On the other hand, this design can easily sustain the impact loads from PM particles generated because this profile is sustained in ocean waves.

The small corners generated by this profile also play an important role in storage of the debris. The overall curved shape of the cavity in the cone is helpful for aerodynamically guiding the PM particles.

In other hand to enhance more effective working area, honeycomb structure encouragement is taken. The hexagonal structure created by honey bees, known as honeycomb, is a breathtaking display of nature's technical ability.

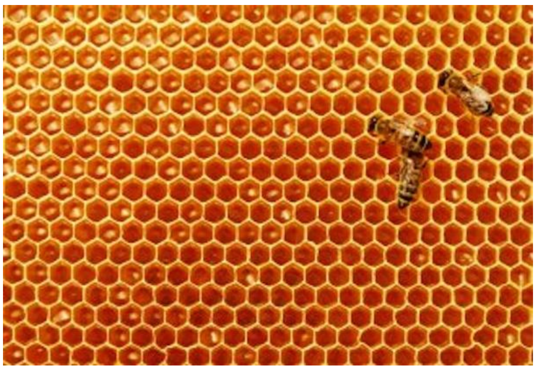

Fig. 4: Natural Honeycomb structure [20]

The worker bees gather and process the microscopic flakes or scales that are first created by beeswax using their mandibles, or mouthparts. They chew the wax to make it softer, and then they shape it into the hexagonal form that characterizes honeycomb cells.

This structure has the ability to stick and carry the small particles inside it which is the need of this development.

4. Design Concept - Dust Collector

As mentioned in the above explanation with the use of bionics concept of sea shells the cover shape is designed using CAD tools. Siemens NX is used for design conception and modelling of this collector as shown in Fig. 5.

It contains n-number of absorbing walls/fins and outer shape of the cone which is finally meet at one small corner area for storage of PM particles generated from the brake.

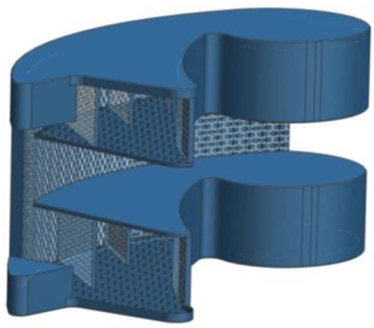

Fig. 5 Internal hexagonal structure inspired from Honeycomb

The cover's outer shell is made to imitate a Nautilus shell's spiral form. This design offers a smooth and aerodynamic surface for airflow around the brake caliper, making it both visually beautiful and practical. Aluminum alloy or composite materials, which are robust and lightweight and ideal for automotive purposes, can be used in the construction of the cover. These materials ensure the lifetime and efficacy of the cover in challenging operating situations by providing strength, resistance to corrosion, and thermal stability.

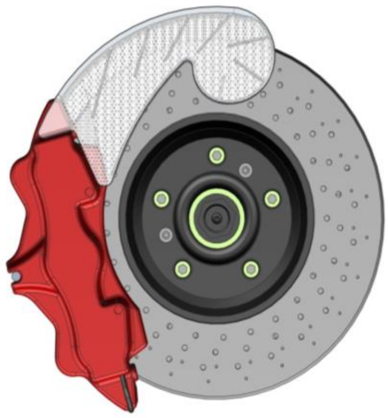

Fig. 6: CAD design showing internal Fins of the dust collector

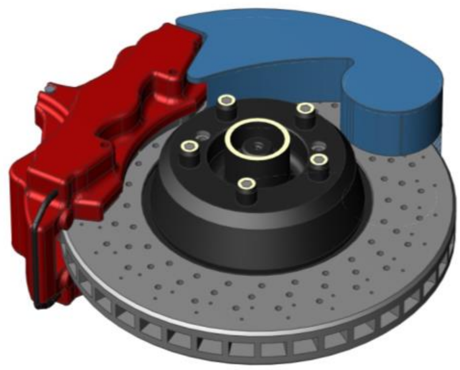

Fig. 7: Dust collector assembled with OEM Brake Disc Caliper

Additionally, the fins and inside structure of this cover can be made of glass wool honeycomb structure. The proposal of implementation of glass wool with honeycomb structure is to enhance the complexity of surface area to maximize the rate of PM collection. On the other hand, the glass wool has desired properties like light in weight, heat resistance, Acoustic insulation and flexibility in molding.

The glass wool's fibers form a dense network with plenty of tiny gaps and passageways as airborne particles flow through the honeycomb structure. The fibers catch and hold on to particles as the air passes through these gaps. The fibers' tiny size and large surface area make them more efficient at trapping particles, even those in the 10 µm size range, which is commonly categorized as fine particulate matter (PM10).

Fig. 8: Glass Wool Sheet [21]

Glass wool is an excellent material for capturing tiny brake parts and particulate matter produced during braking because of numerous advantageous characteristics. The tiny, intertwined strands that make up glass wool have sizes that range from a few micrometers to tens of micrometers. This arrangement of fibers forms a dense network with many of tiny openings and passageways, offering a lot of surface area for collecting particles. Glass wool has a large number of open gaps between its strands, making it very porous. Because of its porosity, the material enables air to flow through it while keeping particulate debris contained in the interstitial spaces. It come into touch with air that is moving or particulate matter can become electrostatically charged. By attracting and capturing particles with opposing charges, these electrostatic charges improve the material's filtering effectiveness. It has a high surface area-to-volume ratio due to its fibrous structure, which increases its ability to trap particles. There are many of places for particle adhesion and deposition on the broad surface area, which raises the possibility of efficient filtering. Because of its thermal stability, it is resistant to melting and deterioration at high temperatures. Glass wool is suitable for applications ranging from -195ºC to 135ºC. However, for some special applications it can able to bear up to 450ºC with binders [6]. This feature is essential for automotive applications since heat generated during braking may compromise the filter material's integrity and effectiveness. It is resistant to deterioration from chemicals, moisture, and exposure to the environment since it is chemically inert. This guarantees the filtering material's long-term efficacy and durability under a range of operating circumstances. To maximize filtering effectiveness for certain particle sizes and concentrations, glass wool materials may be developed with varying densities and thicknesses. Glass wool layers that are denser and thicker can have a higher filtering capacity for capturing tiny braking materials. So, on conclusion inner area material is chosen to be made of glass wool.

After material selection Convenience for after-sales and maintenance is the most crucial consideration in the execution of any new design adjustments. Some expectations are taken into account in order to meet the long-term usage of the designed dust collector without the need for maintenance.

The vehicle's make, model, and brake pad manufacturer can all have an impact on how thick a brake pad is for a light motor vehicle (LMV). When they are brand-new, the thickness of brake pads for light motor vehicles typically falls between 8 and 15 mm. The friction material's face area varies depending on the manufacturer and vehicle model ranging from 5000 to 7000 mm2. [13]. Therefore, volume consideration has already been made to hold more material than the volume of recently installed brake pads. It will fit within the cover with ease if there is any foreign material other than brake pads.

For a lengthy product life, environmental factors are also taken into account. It is suggested that the dust cover's outside be made of aluminum alloys, with glass wool honeycomb covering the inside fins and compartments. hence the likelihood of the outer shell oxidizing will be reduced. However, glass wool is the greatest material for a working environment since it is heat resistant and has additional qualities like moisture and sound absorption.

Additionally, applying a liquid silicon gasket to the brake caliper and cover to provide water proofing may also be recommended. Due to the fact that they have the advantage of a material that repels liquids, can withstand moisture, and maintains a watertight seal.

5. Scope of recycling

As the glass wool and aluminum are both readily recycled, the dust cover construction material is completely recyclable.

The recycling process of aluminum begins with the collection and sorting of aluminum scrap from various sources, including manufacturing leftovers and end-of-life products such as vehicles, building materials, and consumer goods. Aluminum cans are a significant contributor to recyclable aluminum scrap. The collected scrap is then sorted based on alloy type, grade, and impurity levels, using manual methods or advanced technologies like eddy current separators and air classifiers. After sorting, the aluminum scrap undergoes pre-treatment processes to prepare it for melting. These processes include baling, shredding, crushing, granulating, decoating, and demagnetizing.

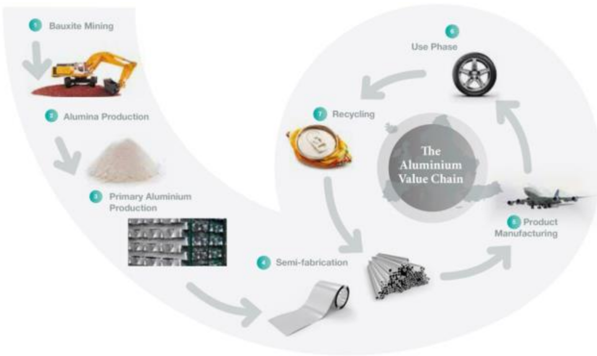

Fig. 9: Life Cycle of Aluminium [24]

Pre-treatment enhances the density of the scrap charge, removes contaminants, and reduces particle size, resulting in faster melting, cleaner metal, reduced dross formation, and lower energy consumption [23].

Next, the pre-treated aluminum scrap is melted in various furnace types, depending on the type of scrap and desired metal quality. Fluxes are added to bind and absorb impurities, which are removed as dross. Additional refining processes like flux injection, degassing, and chemical filtration further purify the molten aluminum alloy, producing refined aluminum alloy suitable for casting or reprocessing [23].

The molten recycled aluminum is then cast into solid forms such as ingots, sows, or directly into sheets or extrusion billets. Different casting methods like direct-chill casting, book molds, continuous casting, and twin-belt strip casting are utilized based on the intended use of the recycled aluminum alloy. Overall, the recycling process of aluminum involves several steps aimed at efficiently transforming scrap into high-quality recycled aluminum alloy for various applications [23].

Glass wool consists of glass fiber and phenolic resign as a binder. Approximately two hundred thousand tons per year of glass wool waste are disposed from the construction site and the production factory of glass wool [7].

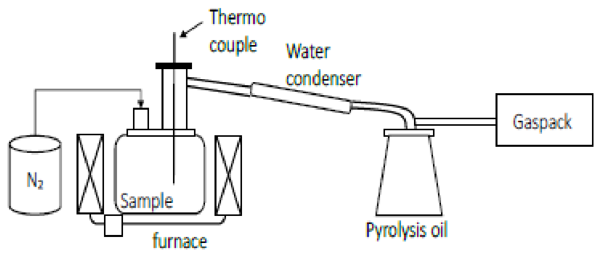

Fig. 10: Experimental apparatus for this experiment [8]

By using pyrolysis with sodium hydroxide, waste glass wool can be decomposed by converting the resin into the gases, such as hydrogen and methane, and glass fiber into soluble salt to be extracted into the solution. Waste glass wool can be decomposed by pyrolysis with 3 times weight of NaOH to the sample above 400 degrees Celsius for 1 - 6 h. In the new study, it is given that recycling technology of waste glass wool insulation material using pyrolysis with NaOH. By using sodium hydroxide, removal of gasification of phenolic resin by catalysis of sodium hydroxide and conversion of glass fiber into sodium silicate by reaction of sodium hydroxide. The gas is used as a fuel, and the sodium silicate salt is dissolved in an aqueous solution and recovered as a silicic acid component (silica component) [8].

During brake assembly service, the dust cover can be cleaned using compressed air in accordance with design considerations and reused.

Five-axis milling machines are the most ideal for achieving the required shapes with higher precession, accuracy and good surface finish when manufacturing the outer cover. Nonetheless, manufacturing techniques such as sheet metal fabrication process and casting canalso be employed.

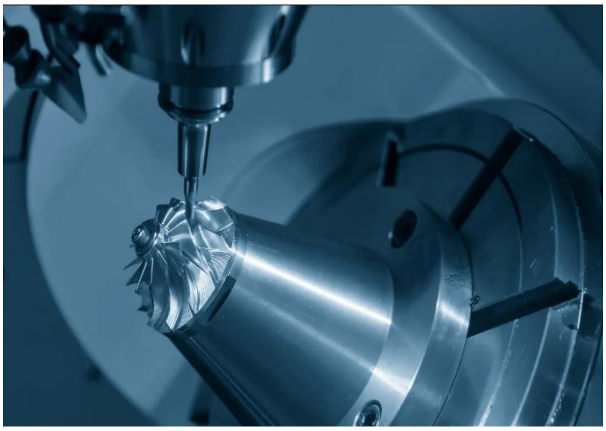

Fig. 11: Illustration of Five-axis milling m/c [22]

6. Estimation & Costing

The price of the product plays crutial role in the market. Especially in this competitive market where affordability, effectiveness and quality all these three aspects to be considered equally. Concerning the affordibility, the cost of the product depends on manufacturing process, type of materials used and selection of sources for raw materials, service providers and inventory purchase.

Item	**Price**	**Cost for required qty/service**
Aluminium 6061	€3/kg	€55
Glasswool	€10/m^2	€5
Machining	€60/hr	€60/hr
Miscelleneous	€5	€5
Finalizing the product (Post processing and assembly)	€15	€15
Total		**€140**

The total cost of manufacturing the dust collector is estimated to cost approximately €140. The mentioned cost is the approximate estimation based on the data available on the internet.

7. Conclusion

In conclusion, creating a dust collector with bionics inspiration specifically, emulating the designs of seashells and honeycombs offers a viable way to address the environmental issues brought on by particulate matter emissions from automobile braking systems. The developed dust collector provides a viable and efficient way to reduce air pollution caused by braking operations by imitating the effective particle-trapping systems seen in nature.

A new method of improving particle capture effectiveness is shown by the dust collector's inclusion of tiny internal chambers which are created with fins that are similar to those seen in seashells. These compartments allow the dust collector to efficiently capture and store particulate matter particles released during braking, minimizing their dispersion into the surrounding environment. The dust collector also uses interception and impaction concepts inspired by honeycomb architectures.

Furthermore, the dust collector's readily adjustable and modular design guarantees smooth integration with cars' current braking systems, making it compatible with a wide range of vehicle types and configurations and enabling wider application. The viability and practicality of integrating bionically inspired ideas into automobile engineering methods to tackle environmental issues is shown by their accessibility.

In Summery, the suggested dust collector offers a concrete step toward the creation of cleaner and healthier surroundings, marking a substantial breakthrough in the field of sustainable transportation technology. We can take use of nature's inventiveness to create novel solutions that not only reduce pollution but also foster harmony between human activity and the environment by utilizing biomimicry and bionics. Future generations might benefit greatly from good transformation and a more sustainable future if bionically inspired ideas are further explored and used.

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