ANALYSIS AND MODELLING OF AUTOMOTIVE AIR FILTER AS A SUBSTITUTE FOR POWERCORE ITEM

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Abstract: *Analysis of PowerCore automotive air filter was made and development of new alternative air filter was performed by increasing surface area of filtering material. New shape of construction of air filter was suggested by introducing double-layer filtering material. It was determined that effective surface area of the new design of air filter was increased 1.5 times comparing with the patented PowerCore item of the same size. Efficiency and strength of the new design air filter was evaluated calculating air flux rates, deformations and displacement in SolidWorks environment.*

Keywords: AIR FILTER, AIRFLOW SIMULATION, DOUBLE-LAYER STRUCTURE

1. Introduction

The latest design of PowerCore produced by Donaldson's uses the same straight-through airflow and high-density filtration system as the original PowerCore, however is, reportedly, 30 % more environmentally friendly [1]. The latest design compared to other filtration technologies, is noticeably different in shape, colour and style. PowerCore is available in round and racetrack shapes, its compact, metal-free, cartridge-style design traps contaminants inside the structure for easier and cleaner servicing [2]. Donaldson PowerCore media technology can utilize options such as a secondary seal, protective wraps, and safety filter to enable increased airflow and system efficiency for peak performance in all conditions [3]. This happens that the axial flow air filter avoids turbulences by allowing the aerosol to flow straight through the filter. It leads to the decrease of potential pressure losses [4].

However, PowerCore air filters have disadvantages – they collect dust particles inside the tubes of the filtering material [4]. One of the possibilities that these particles could not move into the engine is a creation of nanofiber structure of filtering material [5-7]. Also the overlarge contaminating particle, depending on its size and shape, can jam the one or several of air filter tubes, thus shortening its lifetime.

The aim of our work was to design a new construction of the axial flow air filter with the elimination of the disadvantages mentioned above and improved performance.

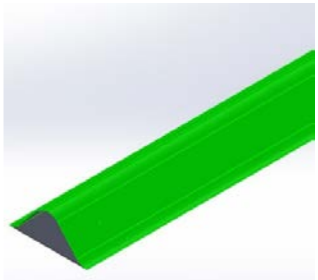
2. Methodology

After reviewing and analyzing the technical literature, a round shape PowerCore design air filter was selected (Fig. 1, a). The filtering material of this filter is a specific one since it has a different design and is made from a plurality of tubes. On purpose to measure the surface area of the filtering material, it is necessary to count the number of tubes (equal: 3430 units), to model the profile of one tube, and to measure the area of its filtering surface as well (equal: 0.0018 m^2). One tube 3D model (Fig. 2, b) was designed using Solid Works 2017 software. This software was also used for other necessary calculations that were needed to create a new design air filter. The surface area of the filtering material of PowerCore item was calculated:

$$S = \frac{3430}{2} \times 0.0018 = 3.087 \text{ m}^2$$

Calculated surface area of filtering material used in PowerCore item was used as an initial object for the further calculations creating a new air filter design.

Applied equipment for experimental research: 3D printer "EOS Formiga P110" for printing of plastic specimens for determination of mechanical characteristics; Tinius Olsen, a universal material testing machine H25 KT, designed to determine the mechanical properties of stretched and bent printed samples from plastic PA2200. The determined plastic characteristics were used for modelling of the air filter, filtering material, fixing elements, for the calculation of their strength and deformation, and the influence of incoming air flows.

a *b*

Fig. 1 *Original PowerCore design air filter in round shape: a) ready-to-use product; b) model of filtering material single tube*

3. Results and Discussion

3.1. Modelling of new design automotive air filter as a substitute for PowerCore item

Depending on the overall dimensions of the air filter, a round-shape design of an alternative air filter was designed, in which the Power Core filtering material structure was replaced with a folded double-layer filtering one (Fig. 2, 3). The modified air filter design allowed to increase the surface area of the filtering material. It was calculated to be 4.677 m^2, where the surface of the first row was 2.668 m^2 and the second was 2.009 m^2.

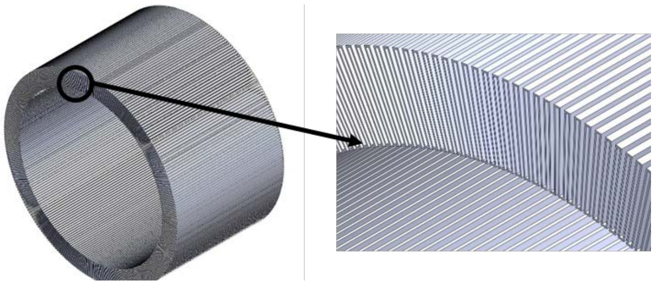


Fig. 2 *3D model of pleated filtering material of round-shape outer ring*

The surface area of our alternative structure of the air filter designed with a double-layer pleated filtering material was compared to the surface of the same shape Power Core item. It was found to be 1.52 times bigger comparing with the surface area of PowerCore item. Based on the results of simulation and computation, the proposed double-layer air filter has very light impact on the cost of production, but presents almost 1.5 times bigger area of the filtering surface. This area can be changed depending on the amount of pleats.

Simulated double-layer air filters should have two unique lids, two layers of filtering material, the inside of which is covered with a plastic mesh for increasing of reliability. The exterior of the designed air filter is 20 mm smaller than the selected PowerCore air filter, so the airflow does not go along the filter, but covers the bottom lid. Newly engineered air filters are expected to increase durability due to approximately 1.5 times bigger surface area of the filtering material.

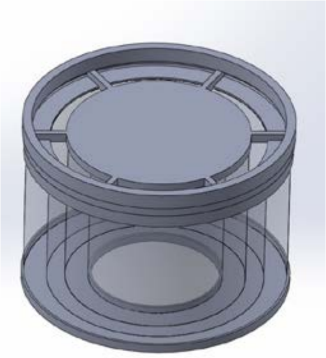


Fig. 3 *Optimized design for a round shape double-layer air filter*

When designing of a new construction of air filters, it is very important to study the distribution of airflow in the filtering material. This test is necessary in order to effectively use all surface area of the filtering material. Therefore, in order to investigate what processes are carried out in a simulated double-layer air filter, a calculating model with boundary conditions for analyzing airflow distributions was compiled. Computational schema for airflow calculation is presented in Fig. 4.

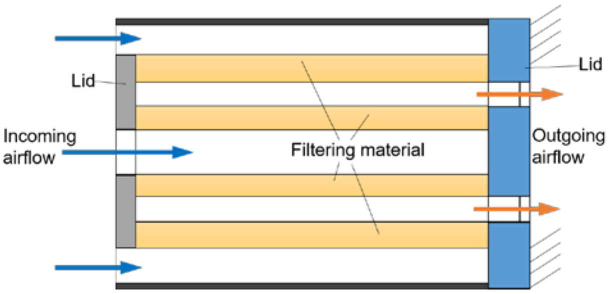


Fig. 4 *Computational schema for airflow calculation*

For the engineered air filter, a frame was created in which a new air filter was placed in the virtual space. During the calculation, the boundary conditions were set: air temperature 20 ºC, air pressure 101325 Pa, air speed at the modelled frame output – 30 m/s. The result of the calculation is presented in Figure 5.

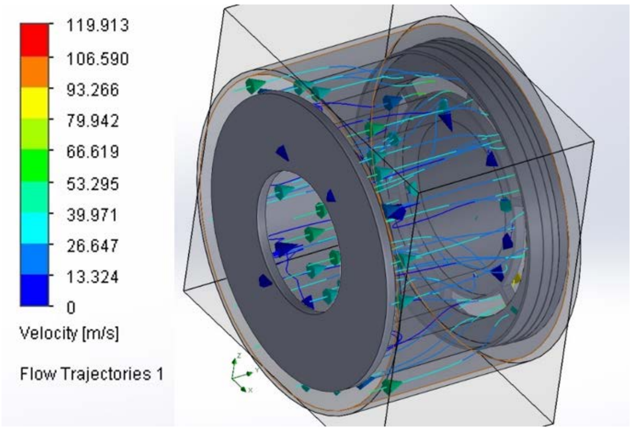


Fig. 5 *Airflow rate distribution in a round shape filter*

The results presented in Fig. 5 show that due to the sharp edges (marked in Fig. 6 by arrows), the maximum possible air turbulence will occur not only around the plastic lids, but also in the smaller filtration ring of the pleated filtering material. In addition, in this area, the surface of the hole is smaller than the surface area of the filtering material. However, this area is not less than the surface area of the vehicle air intake port. Otherwise, the air filter will not provide the required amount of air for the internal combustion engine and will worsen its characteristics. It has also been observed that in this case, the maximum air flow rate is reached near the upper double-layer filter lid. By reaching this limit, the air flow changes the direction and crosses the filtering material, making it difficult to describe what type of air flow is. But in general, the air flow is evenly distributed.

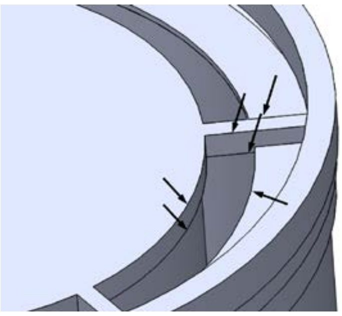
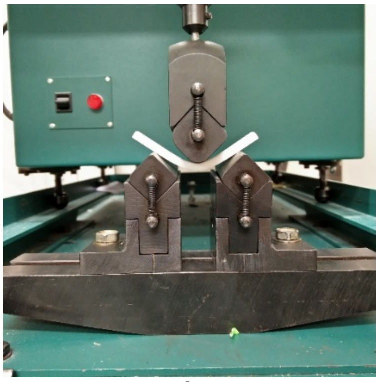


Fig. 6 *Sharp edges of air filter lid*

3.2 Calculations of air filter structural elements during static and dynamic loading

To perform calculations of strength of engineered structural elements and filtering material, it is necessary to determine the mechanical properties of the material used to produce these elements. The following figures (Fig. 7) show polymer specimens and their investigations.

a



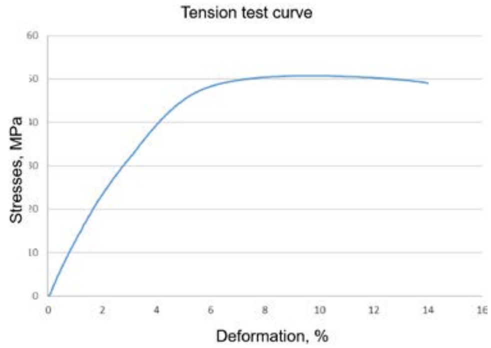
b

Fig. 7 *Determination of mechanical characteristics of printed plastic samples: a) 3D PA2200 sample after tension test, b) 3D PA2200 sample after bending test*

The experimental results revealed the mechanical characteristics of the test material, which were then used for theoretical calculations in the environment of the SolidWorks software. This polymer material was chosen for the available 3D printer that could be used to produce prototype polymeric structural elements. The results of the tests obtained are presented in Fig. 8.

The tensile test for polymer specimens has shown their strength ranges from 50-51 MPa. Meanwhile, the yield point was about 32 MPa.

The bending specimens reached a maximum force of about 200 N. This force was determined when the punch had moved 11 mm distance in the direction of the Z-axis (bending direction). The bending specimen did not crack and did not break, but remained deformed after unloading. This experiment showed that the material was sufficiently plastic to resist dynamic loads occurring during exploitation.



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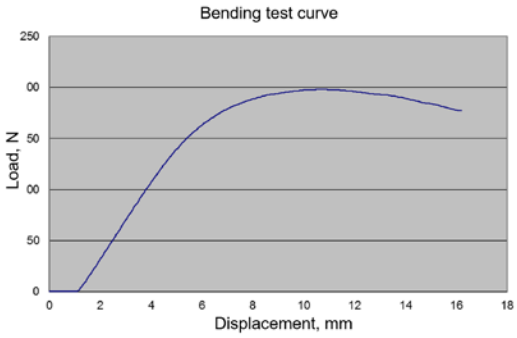


b

Fig. 8 *3D PA2200 deformation results: a) tensile; b) bending*

In order to investigate what processes took place in a simulated double-layer air filter, a calculating model with boundary conditions was engineered. It consisted of 62537 finite elements with 100750 nodal points. The filtering material of air filter of round shape double-layered design was loaded with 0.006 MPa. The selected load corresponded to the initial load generated by fully contamination of air filter. When this load value is reached, the air filter must be replaced by a new one.

Computational schema for stress-displacement calculation is presented in Fig. 9. Calculation results are shown in Fig. 10 and 11.

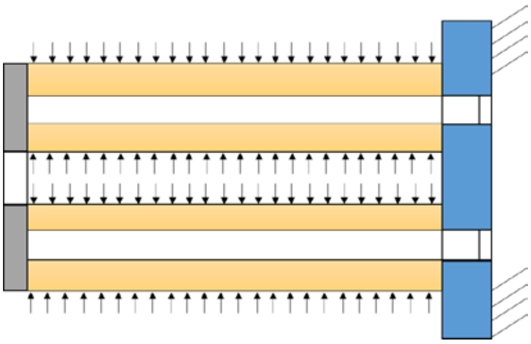
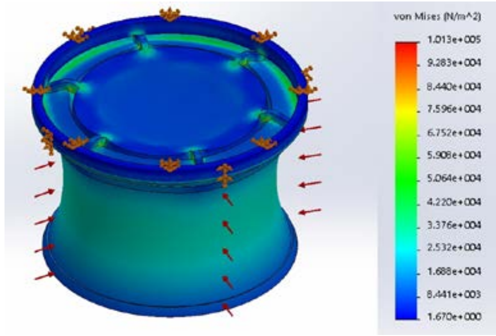


Fig. 9 *Computational schema for stress-displacement calculation*

The results obtained showed that the highest stresses are available in the upper and lower plastic lids, but they do not exceed the permissible ones. Meanwhile, the biggest displacements are determined inside the filtering material. These weak air filter locations require for additional reinforcement elements in order to ensure that the air filter will not be damaged during exploitation and will not damage the internal combustion engine.



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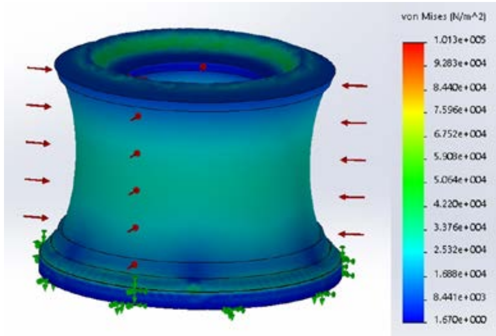

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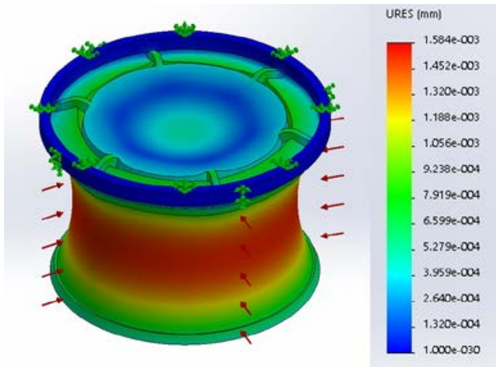
Fig. 10 *Distribution of stresses in a double-layer construction in a round-shaped air filter: a) top view; b) bottom view*



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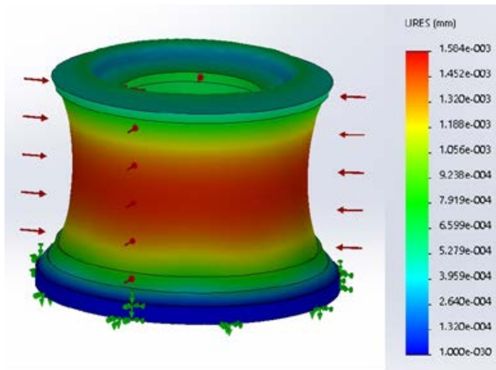

b

Fig. 11 *The distribution of total displacements in a doubler-layer construction in a round shape air filter*

4. Conclusions

Analyzing the results of experiments and sources of scientific literature, such conclusions were made:

- New design of double-layer round-shaped air filter has showed that it's filtering surface has been increased by 1.52 times compared to the similar PowerCore air filter. Increased filtering surface is likely to prolong the life of air filters. On the basis of the results, the proposed double-layer air filter will have insignificant influence on the production costs. The filtering material could be changed depending on the amount of pleats.

- The results of airflow dynamics calculations have shown that the highest possible air turbulence will be due to plastic lids and a smaller filtration ring in the pleated filtering material. It was found that the sharp edges of the lid surface had was one of the causes of the turbulence occurrence, and in addition, surface area of the lid air out-going hole was smaller than the surface area of the filtering material. However, this area is not less than the surface area of the vehicle's air intake opening. However, in filtering materials, the air flow is laminar and evenly distributed.
- The tensile test of polymeric specimens showed that their strength ranges from 50-51 MPa. Meanwhile, the yield point is about 32 MPa. The analysis of the resulting curves showed that the material is sufficiently plastic to resist dynamic loads occurring during exploitation.
- The bending test of polymeric specimens showed that the material was able to withstand the maximum force of about 200 N, when the punch has moved 11 mm in the direction of Z-axis. The bending specimen did not crack and did not break, but remained deformed when was unloaded.

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