Air Filter Element Flow Analysis

Comparison of Aftermarket Air Filter Flow Rates

Team V4 Racing – UWTSD Swansea

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Abstract

In the world performance motorsport optimal air flow into the engine is an extremely important factor for obvious reasons. For the naturally aspirated race engine, any limitations to flow are removed or optimised. However due the way air is inducted from the ambient atmosphere, a form of filtration is a necessity. The debris and impurities in the surrounding atmosphere of the race track can seriously reduce engine life or cause large amounts of damage to internal engine components. Various filtration devices and methods have been created alongside engine development to filter this air flow, whilst maintaining air flow at a maximum. For production engines, where performance is not necessarily the absolute goal, the air filter element has been designed to provide filtration throughout the life of the engine. This has resulted in standard elements being very restrictive of flow into the engine and has therefore opened a large area for aftermarket companies to create "performance" air filtration devices and elements.

This paper will study a number of aftermarket air filter elements that have risen to the pinnacle of the performance motorsport market. Many of them quote increased performance in mass air flow whilst retaining high quality filtration. However, the fact is that any element placed before the intake of an engine will restrict flow. The paper will detail to what extent these aftermarket components have increased flow over the standard production units and amongst them all, what design has the least influence on mass air flow into an engine. Max flow testing will be carried out using facilities within UWTSD Swansea. Following this, samples from each test piece will be examined microscopically in order to gain better understanding of their structure and design. Finally the paper will look at the way filter elements can be implemented into engine simulation software such as Ricardo Wave, and the affects that various constructions of filter have on potential engine modelling.

Introduction

The paper and experiments are being conducted as part of an on-going development project at UWTSD Swansea within the BEng Motorcycle Engineering course. Performance is a key part of the project, which involves the creation and development of a racing motorcycle that competes in a British championship. During the process of acquiring maximum performance from the engine, the team discovered that removal of the filter element and air box structure vastly increased performance. This meant no filtration device against debris was used. This was due to the fact that the performance engine was rebuilt frequently, and the risk of larger debris entering the intake during a crash or other incident, was calculated as being less than the performance benefits it provided.

However further development, and the need for reliability, has caused the project to look for a suitable filtration element. Therefore an experiment was conducted to analyse the various flow rates of aftermarket air filters, to ascertain which brand provided the least effect on flow.

Experimental Procedure

Experiment Introduction:

Having selected a number of aftermarket air filter elements to include in the test, the process in which they would be tested needed to be formulated. This would utilise the facilities of UWSTD Swansea in a number of ways. Firstly the experiment would be entirely based using the SuperFlow SF600 flow bench. This would enable us to test the flow through a number of different air filter samples relative to a pressure difference within the machine. With these results a direct comparison could be made from a percentage of flow figure provided by the machine which is in turn calculated into a rate of flow (CFM or Litres/Sec).

SuperFlow
DYNAMOMETERS & FLOWBENCHES

Test Rig:

In order test all the materials in the same way, without altering in anyway their shape and initial layout, a purpose built rig was designed and 3D printed. The design was developed on CAD Software Siemens NX9 while it was then 3D printed with a MakerBot Replicator 2. The structure of the rig is relatively simple and consists in a vertical tube that has a 95x95mm slot at the top to allow the various test pieces to be inserted and locked in place.

Results

As an independent variable, the pressure was raised by 2 Inches of Water at a time, at flow range 6, and the percentage of flow and Litres per Second (L/s) were the dependent variables. Following the tests, the results are as follows:

SF P08 WP			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	14	6	39.13
4	20	6	55.9
6	24	6	67.08
8	29	6	81.055
10	33	6	92.235
12	35	6	97.825
14	38	6	106.21
16	41	6	114.595
18	43.5	6	121.5825
20	45.5	6	127.1725

K&N Road			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	8	6	22.36
4	15	6	41.925
6	20	6	55.9
8	24	6	67.08
10	26.5	6	74.0675
12	29.5	6	82.4525
14	32	6	89.44
16	35	6	97.825
18	37	6	103.415
20	39	6	109.005

BMC Road			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	11	6	30.745
4	16	6	44.72
6	22	6	61.49
8	25.5	6	71.2725
10	29	6	81.055
12	32	6	89.44
14	34.5	6	96.4275
16	37	6	103.415
18	39.5	6	110.4025
20	41.5	6	115.9925

SF P08			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	16	6	44.72
4	26	6	72.67
6	32	6	89.44
8	36.5	6	102.0175
10	40.5	6	113.1975
12	44	6	122.98
14	47.5	6	132.7625
16	51	6	142.545
18	54	6	150.93
20	57	6	159.315

BMC Race			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	11	6	30.745
4	19	6	53.105
6	24	6	67.08
8	27.5	6	76.8625
10	31	6	86.645
12	34	6	95.03
14	36	6	100.62
16	39	6	109.005
18	41.5	6	115.9925
20	44	6	122.98

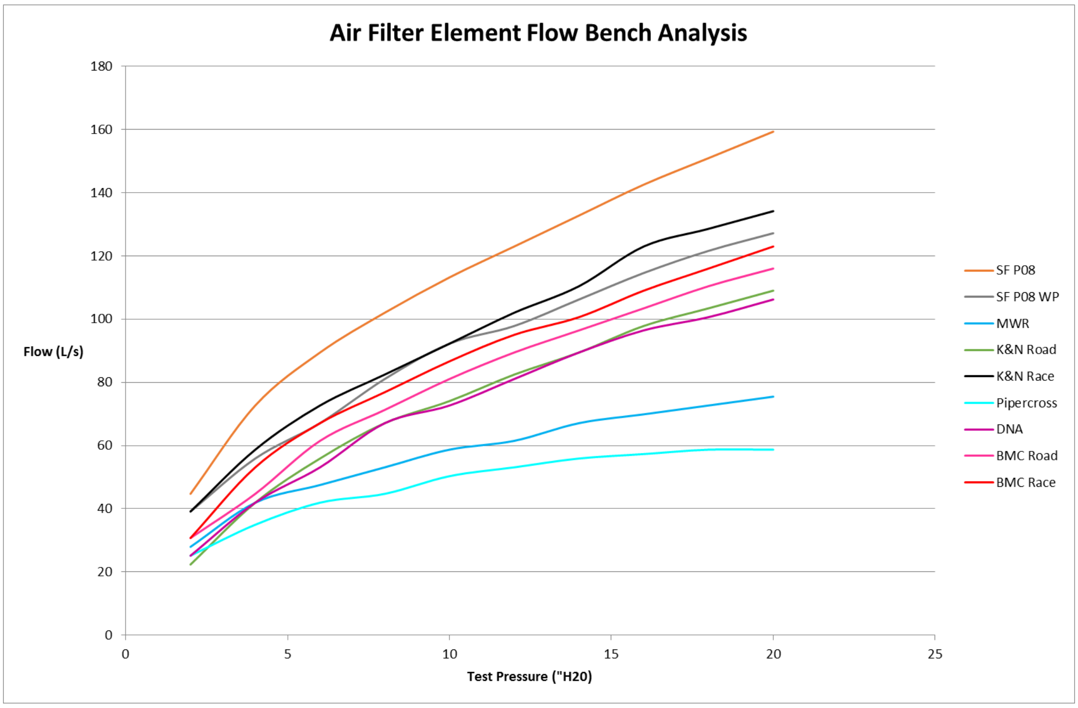
MWR			
TEST PRESSURE	PERCENTAGE FLOW	RANGE	L/s
2	10	6	27.95
4	15	6	41.925
6	17	6	47.515
8	19	6	53.105
10	21	6	58.695
12	22	6	61.49
14	24	6	67.08
16	25	6	69.875
18	26	6	72.67
20	27	6	75.465

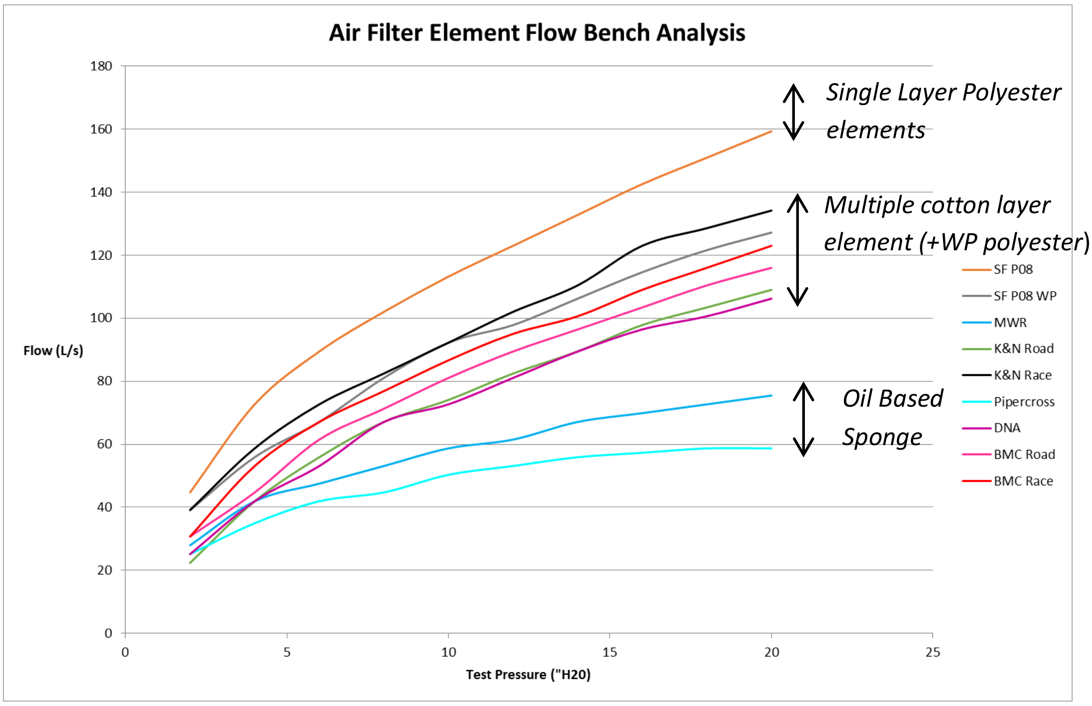
Pipercross			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	9	6	25.155
4	12.5	6	34.9375
6	15	6	41.925
8	16	6	44.72
10	18	6	50.31
12	19	6	53.105
14	20	6	55.9
16	20.5	6	57.2975
18	21	6	58.695
20	21	6	58.695

K&N Race			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	14	6	39.13
4	21	6	58.695
6	26	6	72.67
8	29.5	6	82.4525
10	33	6	92.235
12	36.5	6	102.0175
14	39.5	6	110.4025
16	44	6	122.98
18	46	6	128.57
20	48	6	134.16

DNA			
TEST PRESSURE	PERCENTAGE OF FLOW	RANGE	L/s
2	9	6	25.155
4	15	6	41.925
6	19	6	53.105
8	24	6	67.08
10	26	6	72.67
12	29	6	81.055
14	32	6	89.44
16	34.5	6	96.4275
18	36	6	100.62
20	38	6	106.21

With the results in graphical form we can see just how the various elements perform with respect to outright flow rates. The graphs show three distinct groupings of filter elements. By far the best flow is achieved with single layer polyester filters such as Sprint Filter's P08 material. The second middle group consists of mainly woven cotton gauze, multi-layer filter elements, as well as Sprint Filter's patented water proof SFP08 WP material. Finally the lowest flow came from oil based sponge elements as well as the standard paper filter that was tested.

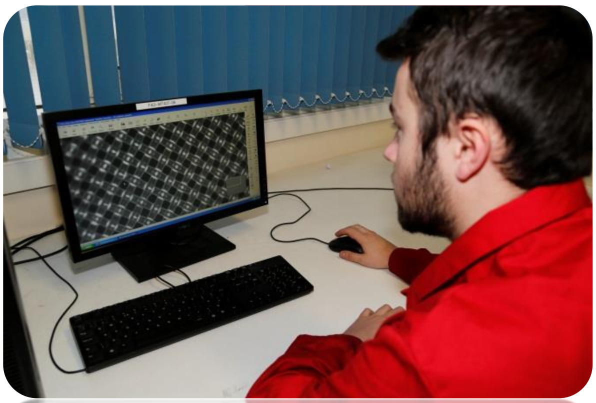


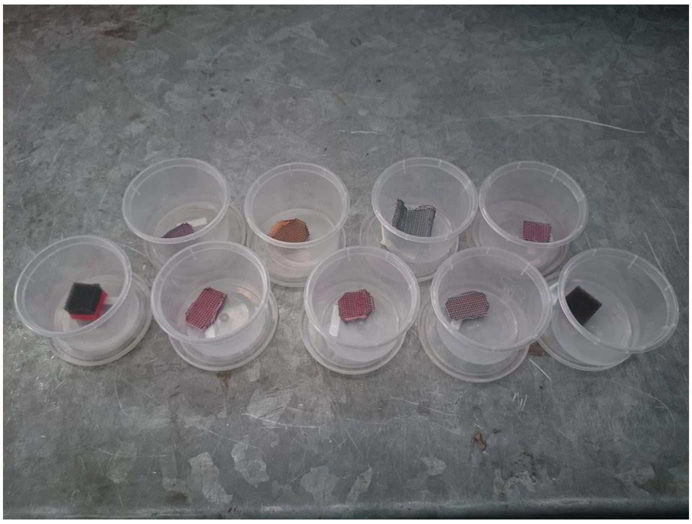


Further Research

Microscopic Analysis:

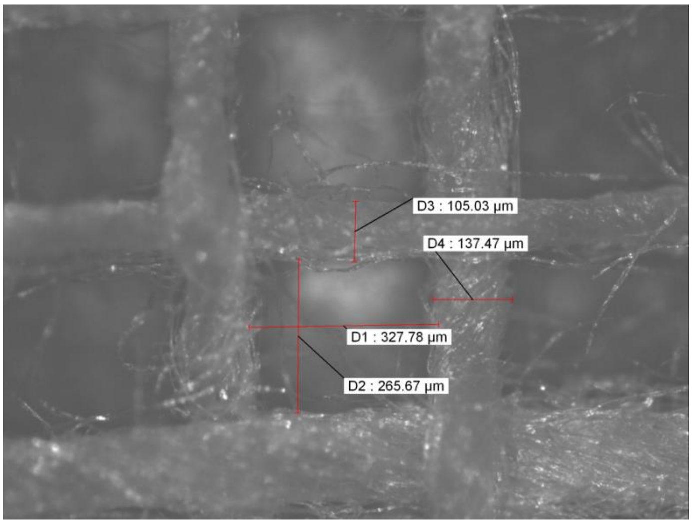
Due to the results that were achieved, it was decided to look deeper into the construction of the various elements that were tested. Especially due to the results achieved from the single layer polyester materials, which to the naked eye appear solid.





Small samples of each tested filter were taken for microscopic analysis.

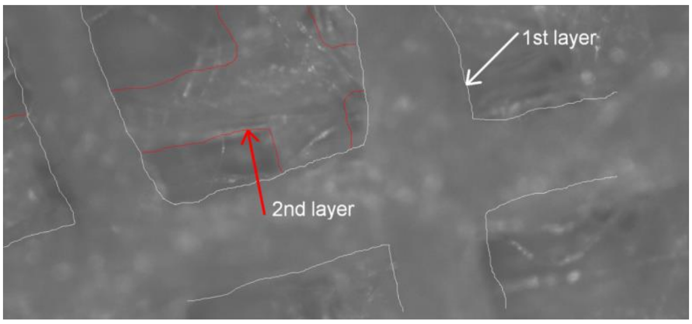
<u>*BMC Race (3 layers):*</u>



This is a woven cotton, multi layered filter element, it consists of 3 overlaid woven cotton sheets.

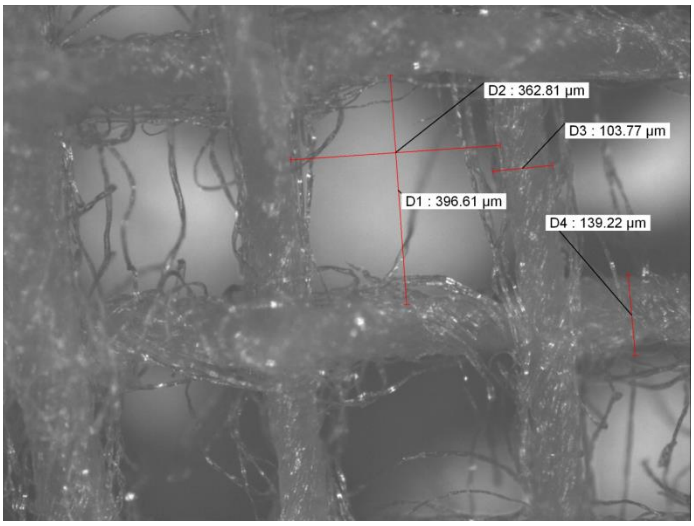
Layers are offset to improve filtration.

Fibre Thickness = 105µm
Weave Area = 86,982µm²



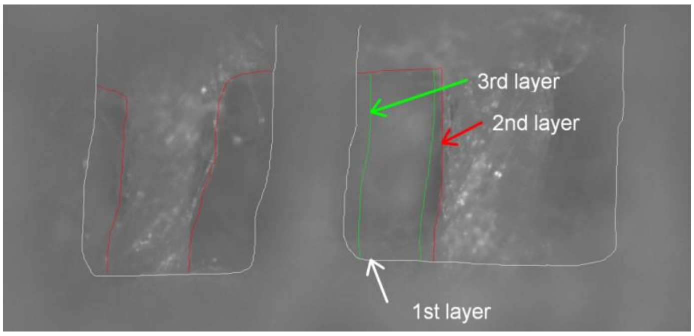
Microscope focus limited to 2 layers.

BMC Road (4 layers):



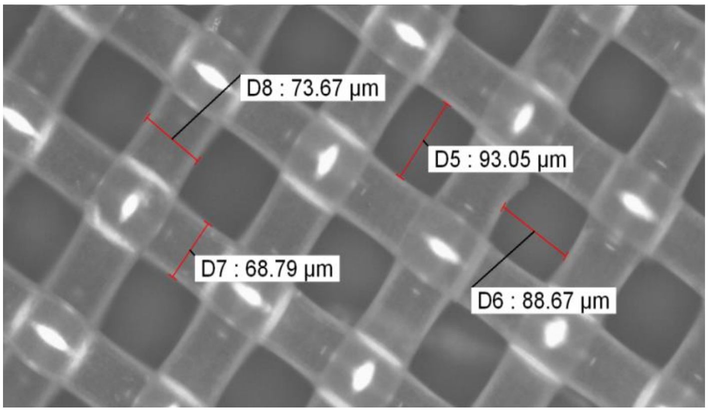
Identical woven cotton construction to its race counterpart however consists of 4 offset layers to increase filtration at a cost of overall flow.

Fibre Thickness = 103.77µm
Weave Area = 143,352µm²



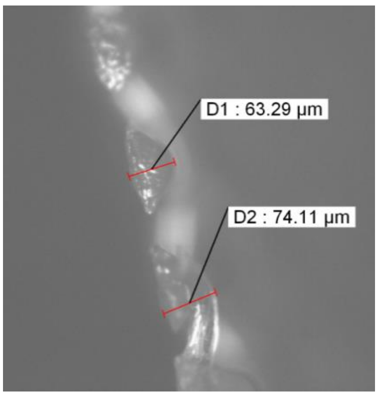
Microscope focus limited to 3 layers.

Sprint Filter - SF P08 (1 layer):



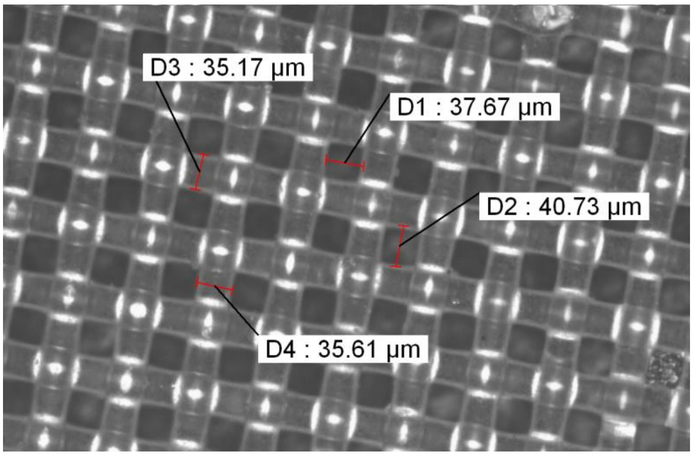
Increased zoom by 10x for SFP08 analysis, Uniformity in weave is apparent from these images. Lack of defects and no requirement to offset layers.

Fibre Thickness = 68µm
Weave Area = 8184µm²



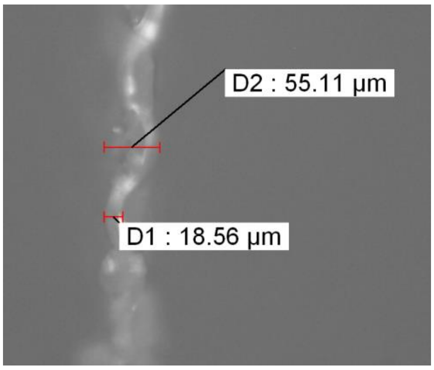
SFP08 element thickness.

Sprint Filter - SF P08 WP (1 Layer):

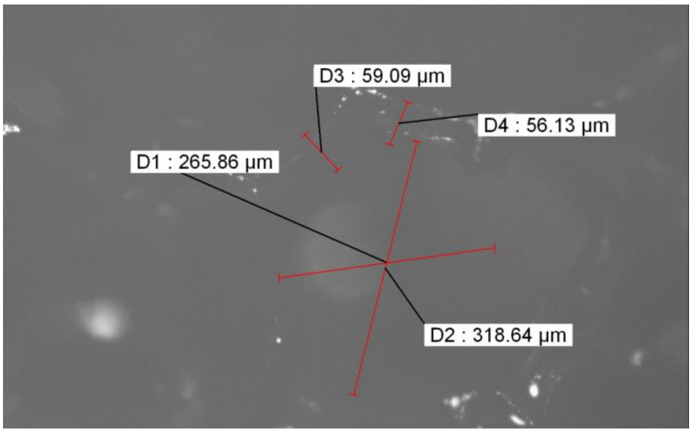


Sprint Filter, SFP08 WP (Water Proof), single layer polyester based element, "Treatment applied to original P08 Material to reduce weave area resulting in waterproof material due to surface tension of water".

Fibre Thickness = 35µm
Weave Area = 1480µm²



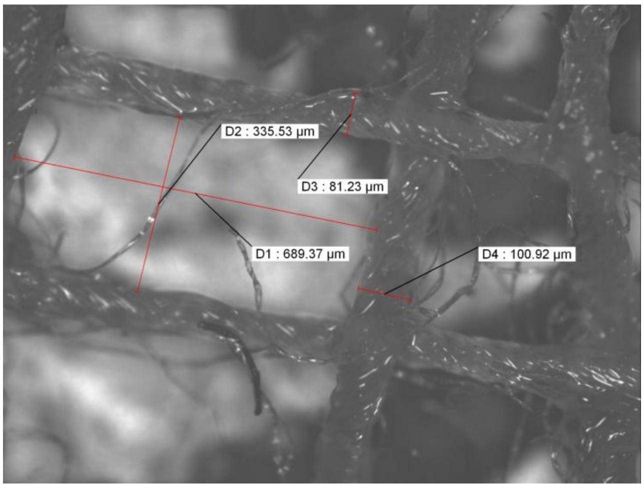
MWR (sponge):



The first of the two oil based sponge air filters. No uniform spacing or weave, random sponge generation.

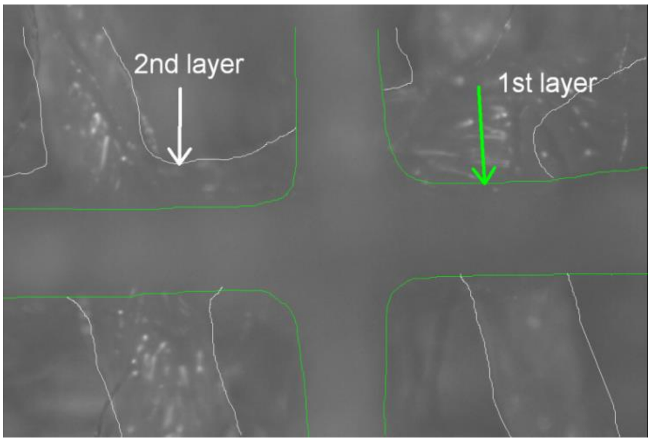
No measurable area or fibre thickness.

K&N Road (4 layers):



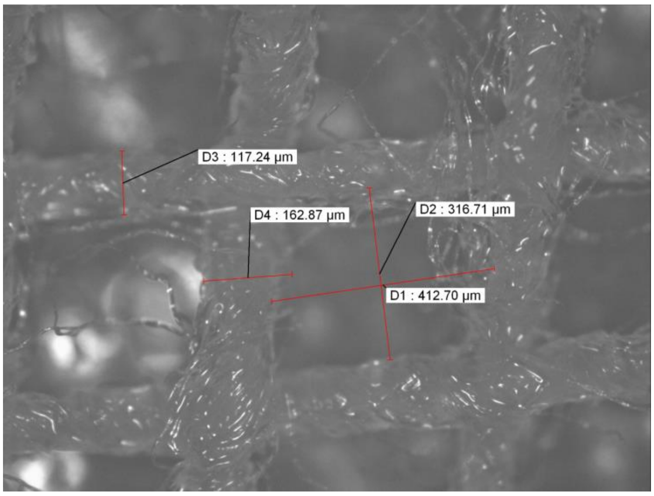
K&N also uses a cotton based woven fibre, like BMC its road filter uses 4 offset sheets of this material.

Fibre Thickness = 100µm
Weave Area = 118,800µm²



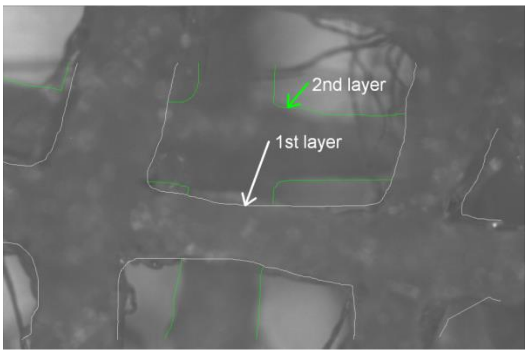
Offset of 1st and 2nd layers.

K&N Race (2 layers):



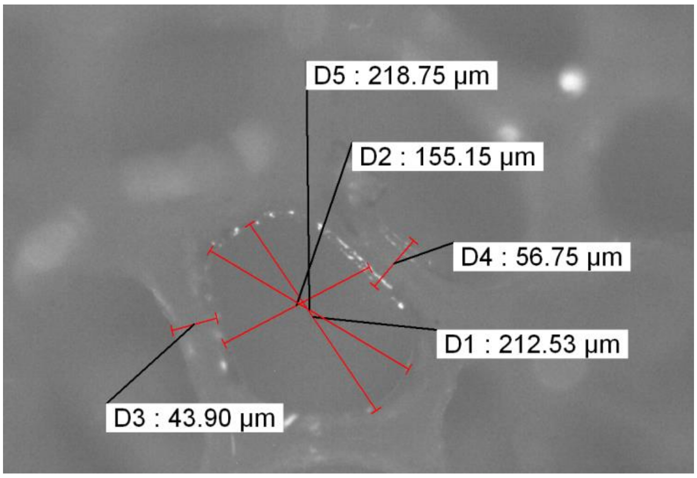
K&N's Race filter is similar to that of the BMC, consisting of 2 offset woven cotton layers. The definition between race and road for many of these filters is simply a reduction in layers.

Fibre Thickness = 117µm
Weave Area = 130,192µm



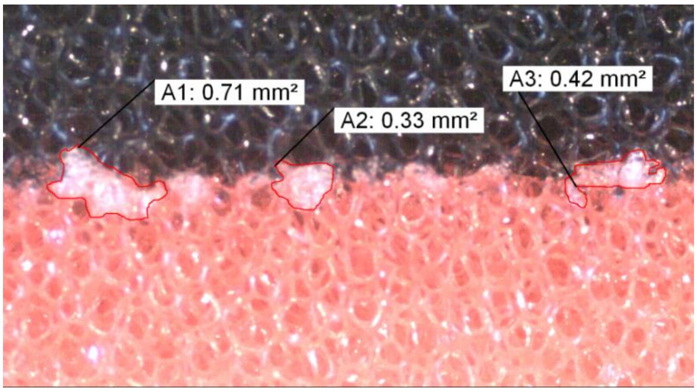
Multilayer offset

Pipercross (sponge):



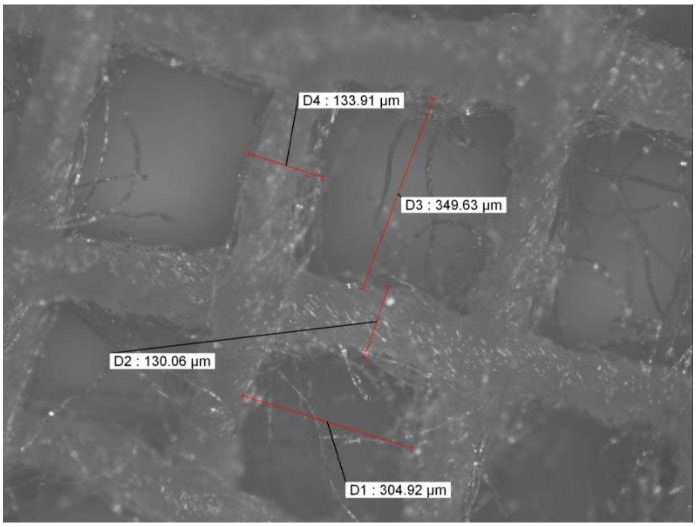
Pipercross is the second of the sponge based elements that was tested, it is made up by 2 layers of sponge.

The area within the sponge seems to be more uniform than to that of the MWR element. However compared to that of the woven elements, both cotton and polyester, it is still heavily irregular.



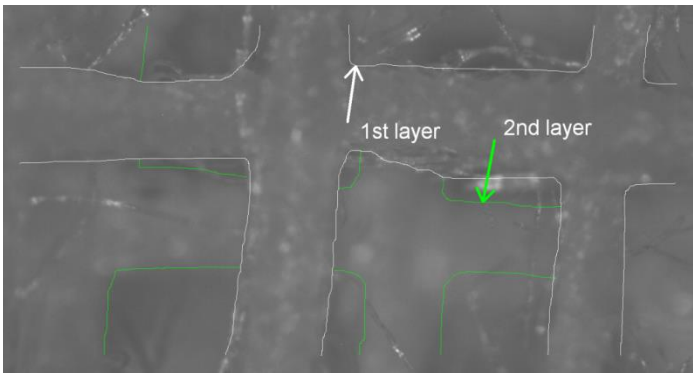
The intersection of the two separate sponge types.

DNA (4 layers):



The DNA filter element is another of the woven cotton elements, again consisting of multiple offset layers, in this case 4.

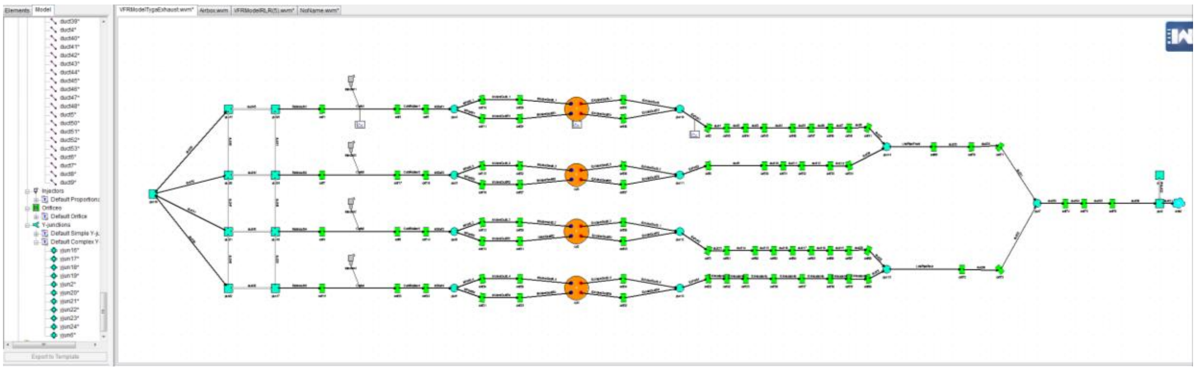
Fibre Thickness = 133µm
Weave Area = 106,096µm²

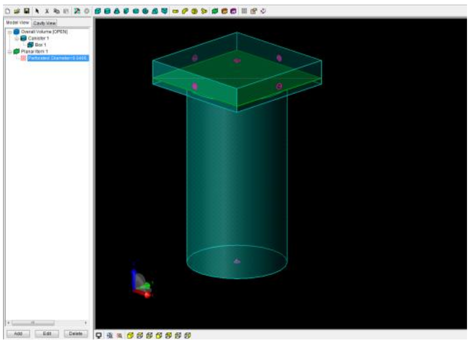


2 of the 4 offset layers within the DNA filter.

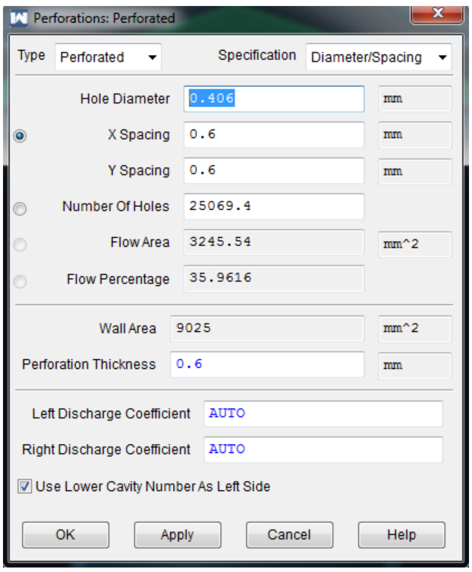
Ricardo Wave Analysis

As another layer to these tests and based on what was found with the microscopes, it has been possible to carry out some tests using the engine simulation program, Ricardo Wave. The simulation of the common cotton based filters is difficult and largely inconclusive. Subesequently a number of people in the industry tend either to ignore air filters when carrying out Wave testing, or simply apply a restriction on the engine equivalent to that which the air filter would produce. These methods are both flawed in their own particular ways. Wave is a system which calculates airflow. The best way to achieve accurate results is with accurate modelling. Previously the authors have simply had to ignore filter elements within the Wave simulations. However with the PO8 material, it has been possible to include them in some preliminary tests.





The same test rig which was used for the flow bench tests has been imported into wave from the original NX drawings, and will be used as the main inlet into the engine. The green element seen here is representing a flattened piece of test material.



It is easy to see how the filter characteristics of the single element filters could be imported into the Wave model. The process becomes increasingly more difficult with each layer of material added. As the layers are not uniformly offset with most of the multilayer type filters, it becomes increasingly more difficult to simulate the air flow accurately through them.

The result of this means that it may be possible, with a well validated model, to limit the amount of real world testing required of a filter as it is much easier to define it's physical characteristics, and therefore simulate in this environment.

Investigation Conclusions

Overall the experiments conducted have provided an interesting insight into the makeup and flow characteristics of some of the leading brands in the performance air filter market. The main output from this investigation has been discovering how well the SFP08 (Sprint Filter) single polyester sheet element flowed compared to its competitors. Not only that, Sprint Filter's patented water proof (WP) filter element, despite it even smaller perforations, flows almost equally as well as the best race level, multi-layer, cotton weave filters. This suggests clear performance advantage in running single layer polyester elements with regards to flow rates. Of these cotton based filters, K&N's race product is by far the leading model.

What was also highlighted was the fact that, due to the polyesters uniform and measurable construction, simulation of this material is possible. This factor opens up a large new area for engine simulation in programmes such as Ricardo Wave.

However none of these tests included any filtration analysis. Despite this, the microscopic tests showed that even with extremely small perforations the SFP08 material still provided the highest flow.

Brand	**Material**	**Max Flow Rate (L/s)**
Sprint Filter	SF P08	159.3
K&N	RACE (Cotton)	134.1
Sprint Filter	SF P08 WP	127.1
BMC	RACE (Cotton)	122.9
BMC	ROAD (Cotton)	115.9
K&N	ROAD (Cotton)	109
DNA	ROAD (Cotton)	106.2
MWR	SPONGE	74.4
Pipercross	SPONGE	58.6

In addition to the findings within this paper, further work into this investigation is being carried out. Future testing is to focus on understanding the effect on volumetric efficiency, of a naturally aspirated engine, due to the various filters that have been analysed in this paper. The testing will focus on gaining results using the static engine dynamometer at UWTSD, and will finish with validation within Ricardo Wave software, as previously mentioned in this paper. The findings are to be published in due course.

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