Project Summary

Natural and Carbon Fibre Composites for Automotive Applications

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Background

Natural materials have been used throughout history in a large range of applications, including textiles, buildings, weaponry, writing implements and transport. With the development of synthetic materials, natural resources were used less in many applications. Synthetic fibres such as glass and carbon have good mechanical properties, which can be adjusted and can also be reproduced predictably. However, a growing awareness of the threat humans pose to the environment in the form of global warming, along with increasing consumption, which produces lots of waste and uses up resources, has led to a return to natural fibres.

The automotive industry is trying to reduce its environmental impact through less energy-intensive production methods, lighter materials, and better end-of-life options. To achieve this, natural fibre parts are being introduced including door panels, seats and bodywork (Shown in Figure 2).

In 2019, Formula 1 announced their intention to be carbon neutral by 2030. F1 may be a key driving force behind the shift towards green behaviour in the automotive industry. The F1 industry often leads the way when it comes to the development of new materials and manufacturing methods, which are later used in the cars we drive every day. James Key (McLaren) describes the industry as “an innovation lab for technology that has transformed not just motorsport, but the automotive industry and beyond.”

Understanding the properties and behaviour of natural fibres is important if the use of these materials is to increase. This project focusses on flax fibres, compared with carbon fibres. Flax comes from the skin of the flax plant, grown in fields as shown in Figure 1. I have evaluated flax in terms of both its mechanical properties, like stiffness and vibration, and its environmental impact if used in vehicles.

Figure 1 - Flax plant before harvest

Figure 2 - Porsche bodywork made from natural fibres

Manufacturing

Carbon fibre and flax fibre samples are produced by Resin Transfer Moulding, where resin is drawn into a mould by a vacuum pump. The carbon or flax fabric is placed inside the mould in advance. The resin enters the mould though the inlet (Figure 3) and is drawn through the fabric to the outlet by the vacuum. The flow rate of resin is controlled by the opening and closing of valves on the pipes.

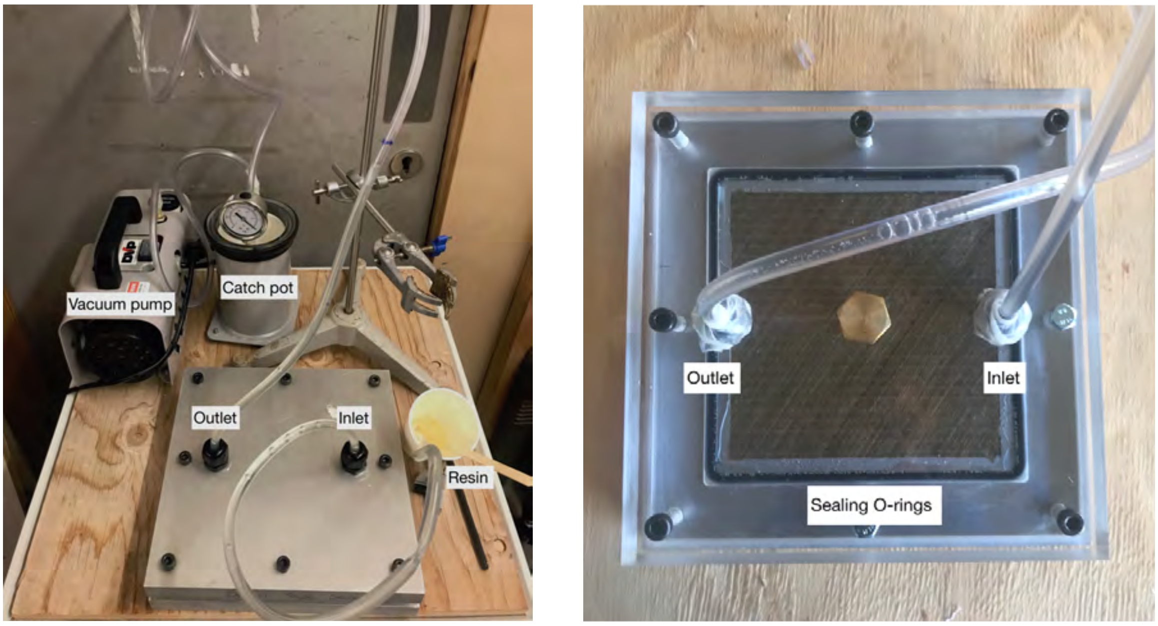

Figure 1 - Manufacturing set-up and close up of fabric in the mould

Carbon fibre and flax fibre composites were produced, along with several hybrid combinations, which had flax sandwiched between carbon and vice versa. There was unfortunately not time to test the hybrid samples – this is an area for future work.

Mechanical Behaviour

The elastic and damping properties of the plates were tested. The key elastic property is the Young's modulus. A high Young's modulus means the material is stiff. The stiffness was found using a vibration method called 'Chladni pattern testing'. This is the oldest form of vibration mode testing, with plates originally made to vibrate using a violin bow. Today the plates are supported on pieces of foam above a loudspeaker, which emits waves to vibrate the plates. The stiffness is found based on the resonant frequencies, the values at which the plates vibrate. The result for flax from these tests is a Young's modulus E of 4.3 GPa for ±45◦ fibre alignment and E = 11.3 GPa for 0/90◦ fibre alignment. These values match those from literature and provide more data to help us better understand flax.

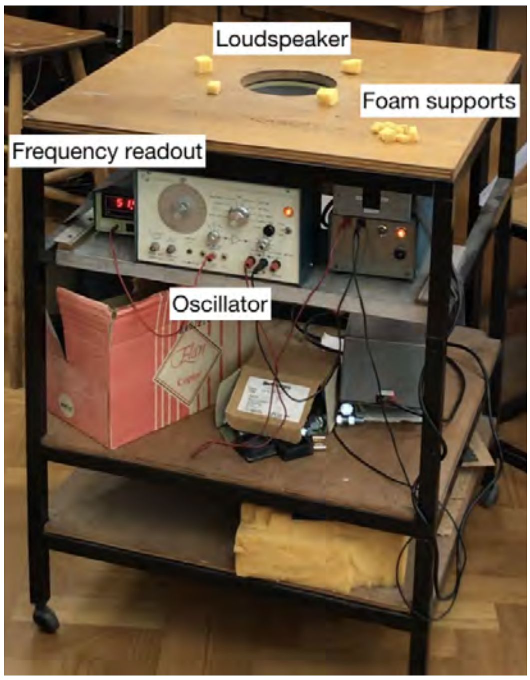

Figure 2 - Chladni pattern set-up

The main reason for the experimental work is to assess the damping behaviour of flax fibres. Damping is the reduction of vibrations by removing energy, often through friction. The high stiffness and low density of synthetic fibres like carbon usually lead to low damping. Both high stiffness and high damping are needed in vehicles. Plant fibres offer high damping, due to bond forming and breaking, which uses energy, and high friction throughout the structure. Better damping could have a big impact on the comfort of an F1 driver and reduce driver tiredness, which can be dangerous and lead to worse performance.

The damping behaviour of the material is described using the 'Q factors' of the samples. A high Q factor means low damping, so lots of vibration. The Q factors are worked out by hitting the plates with a hammer, making them vibrate. The vibrations are measured with an accelerometer. The mean Q factor for flax was 38, compared to 336 for carbon fibre (from Talbot and Woodhouse) - almost 10x lower.

Flax offers much higher damping than carbon. The frequencies over which the damping was tested match to those experienced by the driver in an F1 race. Higher damping over this range could significantly reduce driver fatigue. This is a strong argument for the use of flax in the F1 industry. McLaren is the first to incorporate flax into its design, finding a 5× improvement in damping for its flax racing seat.

Figure 3 - McLaren F1 seat, carbon fibre (left) and flax fibre (right)

Life Cycle Assessment

A key reason for replacing carbon fibres with flax fibres is to reduce the environmental impact of the product. However, it is important not to fall into the trap of assuming that natural materials are intrinsically 'environmentally friendly'. Buzzwords like 'natural' and 'green' are often used to imply environmental credentials, without clear justification. Environmental impact can be determined using Life Cycle Assessment (LCA), where the impact of each stage of a material or products life is considered.

This LCA will consider the Energy Demand and Greenhouse Gas emissions over the four stages of life:

The most significant stage is Cradle to Gate – growing and harvesting flax requires less energy and produces less greenhouse gas than making carbon fibres. The environmental impact of 1kg of flax and carbon is compared in Figure 6. Flax has a lower impact for both energy and greenhouse gas, and the difference is largest for energy.

Figure 4 - Energy and Greenhouse gas results for flax and carbon, over whole life cycle

As well as 1kg of each material, equal volumes (e.g. $1m^3$) of material are also compared. This gives a lower mass of the flax composite because flax is less dense. This results in lower impact for flax in the in-use stage since lower density means a lighter vehicle and so less fuel is required. Therefore, the difference in environmental impact is even more significant with equal volumes of material: 50% energy reduction and 30% greenhouse gas reduction.

Final conclusions

The final results and conclusions from this project, from both the mechanical and environmental perspectives are:

- 10x damping improvement when substituting carbon with flax
- Up to 50% reduction in energy, and
- Up to 30% reduction in emissions when flax is used instead of carbon
- High motivation for the use of flax fibre composites in the automotive industry
- Clear opportunity for Formula 1 teams to pave the way for the rest of the industry