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P6_7 Spider Silk

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Abstract

Spider's silk is often referred to as one of the most amazing materials in nature, with its exceptional strength. It is able to ensnare insects much greater in size and mass than that of the spider that spun the web. In this paper we explore the idea of using a single piece of spider silk to bring a moving car to a halt. We calculated that a Ford Focus moving at 50 mph could be stopped by a single 10 m long thread with a minimum diameter of 1.88 cm.

Introduction

Although some people may consider spiders to be either frightening or an annoyance, they are in fact the genius engineers of the natural world, capable of crafting and creating intricate web structures using their tremendously strong silk. One single strand of this silk can stop a fly in motion [1]. But what happens if we scale this up? We decided to investigate what diameter of a 10 m long strand of spider silk would be required to stop a moving car.

Theory

In this investigation, one end of the silk is fixed securely to the car, the other is attached to a fixed anchor point from which it is unable to be pulled free. One assumption that will be made is that all of the kinetic energy of the car will be transformed into the elastic potential energy within the silk. The kinetic energy is calculated using the following equation:

$$E_k = \frac{1}{2}mu^2 \tag{1}$$

Where E_k is energy in joules, m is mass in kg and u is the initial velocity. Our initial assumption allows us to equate the work done and the elastic potential energy in the silk. Therefore we can use the following equations:

$$E_p = \frac{1}{2}Fx \tag{2}$$

$$\frac{2E_p}{x} = F \tag{3}$$

Where E_p is the elastic potential energy in J, F is the force required in N and x is the stretch distance in m. From here we are able to calculate the cross sectional area using the required force and the breaking stress

$$A = \frac{K}{F_b} \tag{4}$$

Where A as the cross sectional area, F is the required force and F_b is the breaking stress. Finally using the formula for the area of a circle we can calculate the diameter of the thread.

$$D = \sqrt{\frac{4A}{\pi}} \tag{5}$$

Where D is the Diameter.

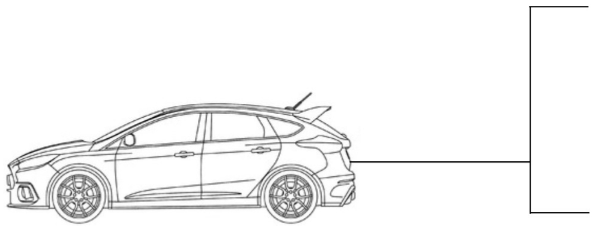

Figure 1: shows the set-up of the investigation having the spider silk anchored at one end, bringing a travelling car from 50 mph to standstill.[2]

Results

We use a Ford Focus as our car, which has a mass value of 1331.3 kg [3] and a velocity value 50 mph (22.35 ms^{-1}). We are considering the silk to reach 16% elongation at breaking point, and have a breaking stress of 1500 million Nm^{-2} [4], meaning the silk increases in length by 1.6 m before breaking. Using the process highlighted in the previous section and these input values, we are able to calculate that spider silk with a diameter of 1.88 cm would be enough to bring the car to a stop from 50 mph.

Discussion

It is amazing that such a thin strand of silk is able to stop a vehicle of this weight at 50 mph. Considering a typical spider silk strand is approximately 0.035 mm [5], by calculating the volume of a 10 m long thread, and that of the thread required to stop the car, it is estimated that around 289000 combined spider silk strands would be needed to have the same strength as the 1.88 cm wide solid strand. When this is compared to a high strength steel in the same situation (with a breaking force of 760 million N/m^2 [6] and using 6.9% [7] elongation at breaking point) we calculate that a diameter of 2.64 cm would be required to do the job. This is a significantly thicker strand than the silk and helps highlight just how strong this material is and suggests we may have much to learn from the natural world.

Conclusion

This mathematical process is not perfect. In this paper we have neglected the weight of the thread itself, which would have an effect on its physical capabilities, albeit minor. We have also made the assumption that when the thread is exerting a force on the car, there are no frictional forces and the car is free-wheeling at this point. In order to further this study we could investigate how different lengths of silk would affect the value of the required diameter. We could also investigate the potential for the use of spider silk as a material in infrastructure, such as the supporting of suspension bridges. Another potential avenue for investigation would be the strength properties of an entire spider web when scaled up to human scale.

References

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