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The Force Required to Stretch Elastigirl's Arm

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Abstract
The 2004 film '*the Incredibles*' features a family of superheroes with different and unique superpowers. This paper investigates the superpowers of Elastigirl (also known as Mrs Incredible or Helen Parr), who has super elasticity and flexibility, as well as being able to shapeshift by utilising her elasticity. The strain, stress, and force required when Elastigirl's arm is stretched to 30m and a thickness of 1mm was calculated. It was shown that her arm would experience tensile strain of 50.7, tensile stress of 10.1MPa, and would require of force of 318.4N to stretch this far.

Introduction
In the 2004 film '*The Incredibles*', a family of superheroes fight to protect themselves and others on multiple occasions. The Incredible family includes Mr. Incredible (Bob Parr) and Elastigirl/Mrs. Incredible (Helen Parr; Figure 1), with their three children Violet, Dash and Jack-Jack, and they all have their own unique superpowers. Specifically, Elastigirl has super elasticity and flexibility, and is seen to be able to shapeshift when utilising these. This is shown when she changes into a basic boat shape during the film to rescue her children and herself from the ocean [1].

Figure 1 – Elastigirl. Image from [2].

It has been calculated elsewhere that the maximum stretch distance of Elastigirl is 30m, and her minimum thickness is 1mm [3]. Beyond this length, Elastigirl may reach her elastic limit and begin to become plastically deformed, before eventually breaking. Using these values, the force required for her to stretch this distance can be calculated.

Tensile strain
The focus of this paper will be the stretching of Elastigirl's arm. It is known that her height is 1.72m (5'8"), and from this her resting arm length was estimated as there is a known correlation between height and arm span [4, 5]. From what is seen in the film, it was estimated that her arm length is approximately one third of her height, and therefore is 0.58m. As previously stated, her maximum arm length, L, is 30m. Calculating the difference between her maximum arm length and her resting arm length, her maximum arm extension, ΔL, is assumed to be 29.43m. These values can be used in Equation 1 to calculate the strain, ε, on Elastigirl's arm.

$$\varepsilon = \frac{\Delta L}{L} = \frac{29.43\ m}{0.58\ m} = 50.7 \qquad (1)$$

Tensile stress
Using Equation 2, the stress, σ, on Elastigirl's arm can also be calculated.

$$E = \frac{\sigma}{\varepsilon} \qquad (2)$$

Where E is the Young's Modulus of her arm, and is assumed to be 200kPa which is the maximum Young's

Modulus of 'normal' dermis skin [6]. The Young's Modulus of the whole arm is likely to differ to this due to the presence of the bone and cartilage, but this value is a reasonable approximation to use. Using this value and the previously calculated strain value of 50.7, rearranging Equation 2 allows the stress on her arm to be calculated as 10.1MPa.

Force

As it is known that Elastigirl can stretch to a minimum thickness of 1mm, the area of her arm at this point can be approximated by a thin rectangle. If this rectangle has a thickness of 1mm, and an approximate width of 3.14cm [7] (assuming the arm is approximately the same width from shoulder to fingertips), the arm cross-sectional area, A, can be calculated;

$$A = 1 \times 10^{-3} \times 3.14 \times 10^{-2} = 3.14 \times 10^{-5}\, m^2$$

This, and the previously calculated stress value of 10.1MPa, can then be used in Equation 3 to calculate the force, F, on her arm.

$$\sigma = \frac{F}{A} \therefore F = \sigma \times A \qquad (3)$$

This gives a force of 318.4N required to stretch Elastigirl's arm to 30m in length and 1mm thickness. If Elastigirl's arm was being stretched by a human pulling it (as shown in the film as her children run away from her grasp and stretch her arms), the acceleration, a, which the person would require to do this can be calculated using Equation 4.

$$F = ma \ \therefore a = \frac{F}{m} \qquad (4)$$

As it was her children that stretched her arms, this calculation is based on Dash. As Dash has a mass of 27 kg [8], the acceleration required for him to create this force and therefore stretch Elastigirl's arm can be calculated and is 11.8ms^{-2}.

Conclusion

In conclusion, if Elastigirl is able to stretch her arm to 30m in length and a minimum thickness of 1mm, the strain on her arm would be 50.7. Assuming that her skin has a similar Young's Modulus to a 'normal' arm, and only considering the skin, the tensile stress experienced by her arm would be 10.1MPa, and the force required to stretch her arm in this way would be 318.4N. In order for one of her children, Dash, to stretch Elastigirl's arm in this way, he would need to run with an acceleration of 11.8ms^{-2}.

References

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