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Unbelievable Tekkers

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Abstract

In this paper we calculate the contact force needed to fracture the surface of a FIFA regulated football. We also determine the speed at which the leg kicking the ball must be travelling in order to generate this force. The force required is 990409 N; to generate this force the leg would have to travelling at over 400mph.

Introduction

The international governing body for football (FIFA) imposes strict regulations for the match ball's physical dimensions and characteristics. According to law 2 of the 'laws of the game' published by FIFA, the match ball must be spherical and have a circumference in the range of 68- 70 cm. The pressure inside the football must be in the range of 58,605 – 107,558 pascals. [1]

Method/Investigation

For the purpose of our model we assume the ball is made entirely of leather and model the ball as a thin walled spherical pressure vessel. We assume that all of the force generated by the leg is transferred to the ball. We also assume that the ball is an incompressible sphere and so no energy is lost elastically to deform the ball. It can also be assumed no energy is lost as heat or friction.

The tensile strength of leather is between 20-26 x 10^6 Pa [2]. We will take the lower bound of this range as it is unlikely the leather used for a football will be the toughest leather.

The stress force on the surface of a stationary spherical vessel is distributed evenly. We consider just the stress in the longitudinal direction to obtain an applied force that would cause the material to fracture. The stress (σ) on the ball can be calculated using the following equation:

$$\sigma = \frac{Pr_i}{2t} \qquad (1)$$

Where P is pressure, r_i is the internal radius of the ball and t is the wall thickness. [3]

We can calculate the radius of a typical football using the circumference range outlined by laws of the game (68-70cm) [1]. We take the circumference (C) as 69cm. We can calculate the radius using the relationship:

$$C = 2\pi r \qquad (2)$$

The radius of a football with a circumference of 69cm is 10.98 cm. We can now calculate the internal radius by subtracting the wall thickness of the ball which we estimate to be 3mm. Therefore the internal radius of the football is roughly 0.107m. We assume the pressure is the upper limit of the range stipulated by law 2 and so the stress on the leather material casing is 191811.77Pa.

We can calculate the applied pressure needed to fracture the leather casing of the ball by subtracting the stress on the surface from the tensile strength which gives us a value of 19808188Pa. Pressure is force per unit area and so we can calculate the force by multiplying the pressure by area. In this case the area is the contact area between the ball and foot. We model the surface of the foot as 5 by 10cm rectangle (area = 0.05m^2). The force required is 990409N.

Using the force calculated we are able to calculate a rough speed the leg would have to be travelling to generate this force. We first must determine the acceleration of the leg using F=ma. We estimate the mass of one human leg to be 15kg and so to generate the force required the leg would have to be accelerating at 66027.3 ms^{-2}.

From this we can then use the equations of angular motion to obtain an estimate for the velocity.

$$a = \frac{v^2}{r} \quad (3)$$

v = 181 ms^{-1}

The leg would have to be travelling at a staggering 405 mph to generate such a force that would result in the fracture of the leather casing of the football.

Conclusion

The force we calculated that is required to fracture the leather casing and cause the ball to deflate is an overestimation. The surface of a football is made of leather (or other similar material) panels stitched together [1]. The tensile strength of leather is the upper limit and is much stronger than the stitching. The stitching would fracture with a much smaller force.

References

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