Theoretical Calculation of Helmet Thickness Necessary to achieve 100g for a 6.2 m/s impact

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The challenge is to determine the minimum helmet thickness necessary to absorb the kinetic energy associated with a 6.2 m/s flat anvil impact such that the peak headform acceleration is 100g or less. For this challenge the following assumptions are made.

- Our target acceleration for this particular calculation is 100g or 981 m/s^2.
- Our initial impact velocity is 6.2 m/s, measured just above the flat anvil. This represents the velocity of the headform at the instant the helmet outer shell makes contact with the rigid flat plate.
- The helmet is made of EPS and absorbs energy by crush.
- The object comes completely to rest as a result of the impact with a final velocity of 0 m/sec.
- The falling object behaves as a solid rigid material and the impact surface is infinitely stiff (i.e. a rigid flat plate).

If we take a fundamental equation for vertical motion of a projectile:

$$V_f^2 = V_i^2 + 2a_y * d \quad \text{(Equation 1)}$$

Where V_f is the final velocity of the object, Vi is the initial velocity of the object, a_y is the constant acceleration of the object in the vertical direction and d is the displacement of the object in the vertical direction. Note that depending on the assumed signs of acceleration, velocity, and displacement the signs on this equation may change with no impact on the final results.

Knowing the final velocity of the object is zero gives us a new form of equation 1:

$$a_y = \frac{-V_i^2}{2d}$$

Inserting our known values into this equation, gives us the following equation:

$$981\ m/s^2 = \frac{(-6.2\ m/s)^2}{2d}$$

Solving for d, we find that d = .0196m or 19.6mm.

Thus for a perfect material generating a constant acceleration, 19.6mm are required to bring a rigid object to rest with a constant acceleration of 100g.

Within the context of a rigid magnesium headform and a helmet made from expanded polystyrene (EPS), this suggests that we would need an EPS helmet that is at a minimum, 19.6mm thick. However, recall that these projectile equations assume that our impacting object performs as a perfectly solid, rigid object, and that the acceleration was in the form of a constant square pulse, thus absorbing a maximum amount of kinetic energy. In reality, we know that an EPS helmet is not a perfect energy absorbing material and in reality the acceleration pulses for a bicycle helmet are typically triangular in shape (see Figure 1). This shape is due to the material properties of the EPS, the geometry of the rigid headform in contact with the inner surface of the helmet, and the geometry of the outer surface of the helmet in contact with the stiff flat impact surface. This means that the helmet absorbs approximately ½ of the energy of a perfect material (i.e. a triangle pulse shape versus a square pulse shape). Consequently, if the helmet absorbs ½ the energy of a perfect material, we must assume that it will take twice the distance to properly decelerate the rigid object. This means that the displacement necessary to decelerate an EPS helmet with a rigid headform that impacts the rigid flat anvil at 6.2 m/s will be approximately 38 to 40 mm.

The full thickness of the EPS cannot be utilized to absorb the impact energy. As the material crushes, resistance to impact increases to a point where it becomes very stiff. This "lockup" point varies between 30% and 70% of the original thickness of the material. To account for this the required thickness grows to between 50 and 60 mm.

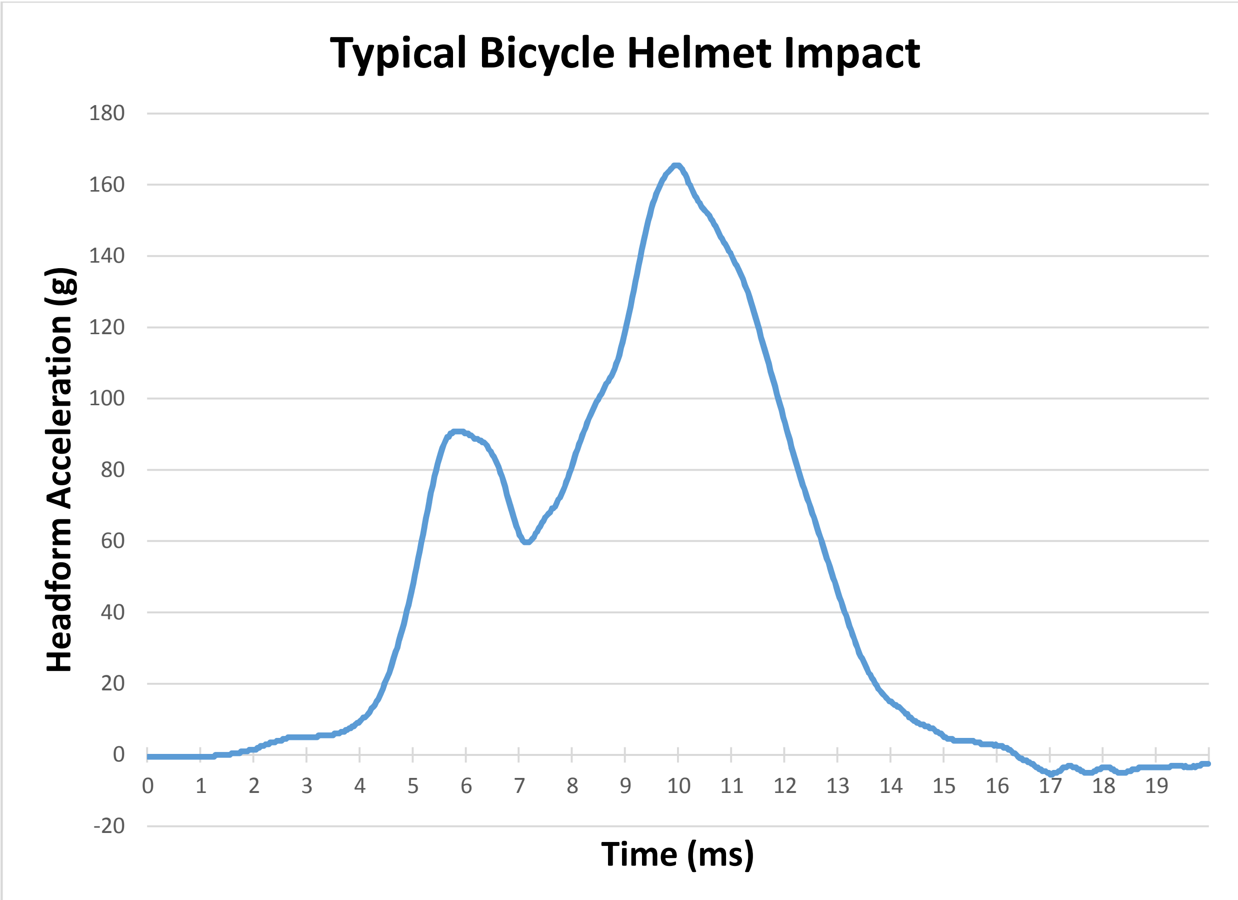

Figure 1: Typical Bicycle Helmet Impact onto Flat Anvil

Unfortunately, we aren't finished just yet because if we have a helmet that is 50 to 60 mm thick, manufacturers want some type of "safety margin" built into their helmets. This assures that given the normal variance in helmet EPS production, specific design features, etc.. they will continue to meet the impact requirements of a given standard at all locations on or above the test line. So if we assume that a manufacturer wants to have 20% of helmet margin after this 6.2 m/s impact, then the helmet must be between 60mm and 72mm thick --- well above the nominal thickness of most bicycle helmets (which is typically 25 to 30mm, sometimes less).

Using this same logic, we can see that if we currently have a 300g pass/fail limit with a typical 25mm to 30mm EPS thickness, reducing the pass/fail criteria by 1/3 is going to require at least triple the typical EPS thickness (or 75 to 90mm).

The physics of a 6.2 m/s impact with a 100g peak headform acceleration requires a perfect energy absorbing material which generates a square acceleration pulse and is a minimum of 20mm thick. At present, no such material exists – only aluminum Hexcel™ comes close when impacted in the appropriate orientation. Existing materials are limited in their ability to absorb impact energy and consequently the only way to effectively absorb the kinetic energy associated with a 6.2 m/s impact and keep the peak headform accelerations at 100g or less is to increase the thickness of the helmet. Unfortunately, this often has a negative effect upon helmet wearing in that most bicycle riders do not want to wear large and thick helmets on their heads. For infants the larger helmets could also adversely affect other parts of the body such as the neck.

Respectfully submitted,

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