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OBLIQUE IMPACT ANALYSIS OF CYCLING HELMETS MADE FROM KENAF (HIBISCUS CANNABINUS) AND FLAX (LINUM USITATISSIMUM) NATURAL FIBER

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Abstract

This paper describes the performance of a natural-fiber-based cycling helmet in an oblique impact with a simulated road surface. The linear accelerations and impact energy of a head form weighing 4 kg were measured and calculated. Helmet standards require helmets to be tested with a simple drop test onto an anvil. The maximum permitted deceleration of the dropped head form is typically 300g, which is equivalent to an impact velocity of 20 km/h (12.5 mph). The two helmets being tested were suspended onto a guided drop-table in the particular desired impact orientation. Just before impact, the test object was released from suspension so it can move unrestrained thereafter. The main advantage of this process is that the object is free to move naturally during impact, which provides for more realistic drop-testing. For oblique impact test, all helmets tested passed the requirement set by EN1078:2007 with linear acceleration measured lower than 250 g in a free fall test from 1.5 m platform. By comparing the resultant linear acceleration with a commercial cycling helmet, Kabuto Aero SL, flax aero helmet shows 11.82% reduction in the resultant linear acceleration with 214.16g. The Kenaf helmet recorded 168.48g, which corresponds to a 30.63% reduction in the resultant linear acceleration compared to the Kabuto helmet and 21.33% reduction compared to the Flax helmet.

Keywords: Oblique impact, cycling helmets

Introduction

In the years to come, the use of helmets will undoubtedly increase. This will benefit the safety of cyclists. Nevertheless, with more helmets involved in accidents and everyday use, the impact tests for today's helmet design must be studied. According to Franklin (2000) early helmet promotion was largely by the helmet manufacturers making claims and counter-claims about the merits of their particular helmet design. In 1987, Dorsch [2] predicted that there would be a 90% reduction in fatalities if all cyclists wore hard-shell helmets. According to Rivara, Thompson, and Thompson (1996) researchers undertook a study at five hospitals in Seattle between December 1986 and December 1987 of cyclists admitted to an emergency room. Of 776 cyclists admitted, 269 had head injuries. 235 of these, and 433 of the 507 cyclists who were admitted without head injuries, completed a questionnaire. The study concluded that bicycle helmets reduce the risk of head and brain injury by 85% and 88%, respectively. Boufous, Senserrick, Stevenson, and Ivers (2011) stated that head injuries due to bicycle crashes are a major factor in accidents. In previous research, Aldman, Lundell, and Thorngren (1978). dropped a complete dummy, held horizontally, onto a rotating turntable of diameter 1 m. They found that for tests on helmets, peak head form rotational acceleration was approximately independent of the tangential velocity component, in the range 0–11 m/s. However, their test rig was bulky and hazardous, while the use of a whole dummy was not essential. Gilchrist and Mills (1996) conducted a tests using a dummy with a realistically flexible neck showed that the head motion in the first 40 ms of an impact is unaffected by the neck. According to the U.S. Consumer Product Safety Commission (1998), standard helmets are subjected to a series of impact tests to evaluate their energy attenuation performance using guided free-fall drop tests. Newton (1988) stated that free drop-testing best replicates the abuse a portable product will experience in the field. The main aim of this test was to investigate the effects of helmets' external shape and impact site on the resulting linear accelerations of the head. According to Mills and Gilchrist (2008) to obtain meaningful results, the helmet must rotate realistically on the headform. Hence, details of the helmet retention system are important. Using a high speed camera, the behavior of the helmet during impact with the platform can be observed.

Helmet Design

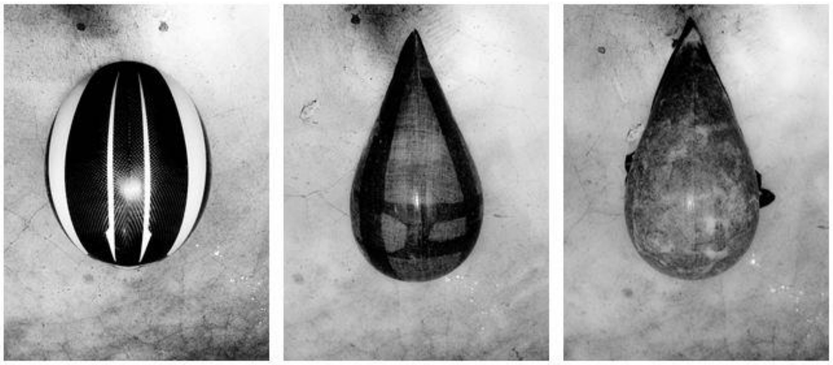
Bicycle helmet design has changed markedly since 1990 Mills (1990). The impact test drop height increased from 1.0 to 1.5 m, when British Standard BS 6863 was replaced by EN 1078 in 1997 (BS EN 1078, 1997). Current helmets have more ventilation holes, are thicker at the rear, and sometimes have a non-smooth external profile. The helmets subjected to oblique impact tests in 2002 had less than ten, large ventilation holes. According to Mills and Gilchrist (2003), by 2005, the number of ventilation holes has increased, and their size decreased. Since a helmet is a compromise between aerodynamics and ventilation, and since aerodynamics are difficult to test, ventilation may become more important than the aerodynamics factor. Normally, protective helmets involve a shell and an energy absorbing layer. Modern cycle helmets normally have a micro-shell, usually between 0.3 and 0.8 mm thick, that is frequently attached to the liner material during the manufacturing process. The micro-shell liner offers little rigidity or load distribution, but may help to sustain helmet reliability in an impact, which may be most important if a second impact occurs in the same accident. Asiminei, Van der Perre, Verpoest, and Goffin (2009) stated that by changing the material used as the liner, it is ideally possible to tune head protection properties for a particular impact condition of interest. However, the extent to which this is done by helmet manufacturers may also be determined by material obtainability and cost. Helmet fit and retention are also considered important, because an unsuitably fitting helmet may not offer the designed impact absorption, and a helmet that is displaced in an impact may not provide any protection at all.

Testing of Helmet

In this test, three different helmets made from different materials, which are carbon fiber, kenaf, and flax, were tested and their specifications are shown in Table 1. One of the helmets, Kabuto AirAttack helmet is a standard manufactured helmet for time trial races. The Kenaf Aerohelmet and Flax Aerohelmet are newly design helmets with new bio-composite material. The top view and side view of the helmet design is shown Figure 1 and Figure 2. The main purpose for this testing is to compare the resulting head accelerations when using the Kabuto helmet and the newly design material helmet. Each helmet is equipped with different interior pads and foam thickness to compare the shell strength of the helmet and attached by Velcro at several sites inside the liner to bridge the gap with the head. A hard shell is likely to distribute loading better under restricted loading conditions, and would be expected to be better than a micro-shell in protecting against penetration of sharp objects. In both hard-shell and micro-shell helmets, the liner will absorb a proportion of the impact energy and distribute the impact loading over a wider area of the head. Both of these structures will lessen the risk of cranium fracture and the risk of skull fracture and brain injury. The quantity of impact energy absorbed will depend on the design of the helmet, the impact tests that the helmet has been designed to meet and the type of surface impacted. In the progression of absorbing a quantity of the energy of an impact, the structure of the helmet is frequently damaged. This is an important characteristic of helmets. If the liner material is flexible, the impact energy that was initially absorbed would be imparted to the head later in the impact, greatly reducing the efficiency of the padding. Liner materials are therefore mainly plastic in their deformation characteristics.

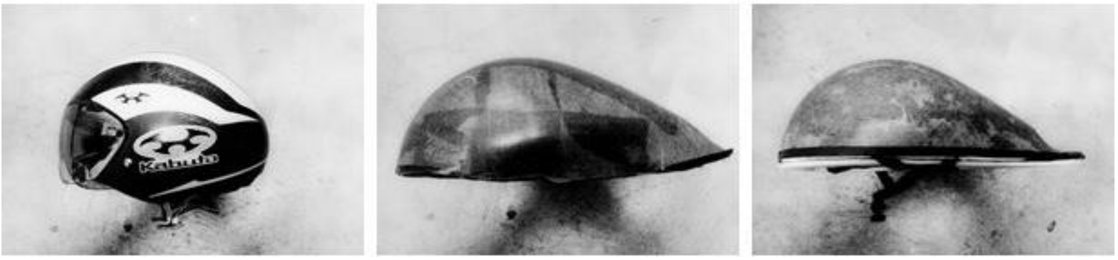
Table 1: Helmet specification.

Model	Kabuto AirAttack	Flax Aerohelmet	Kenaf Aerohelmet
Material	Carbon Fiber	Flax	Kenaf
Total Mass (kg)	0.345	0.315	0.342
Length (cm)	27.5	39.5	41.5
Shell Thickness (cm)	0.2	0.1	0.05
Padding Thickness (cm)	1.5	1.0	2.0



a) Kabuto b) Flax c) Kenaf

Figure 1: Top View of Helmet Design.



a) Kabuto b) Flax c) Kenaf

Figure 2: Side View of Helmet Design.

Procedure

Oblique Impact Test Rig

Bicycling may lead to the dangers of death or severe harm because of head injuries. The suitable utilization of protective helmets can minimalize the danger of death or interminable harm. The protective limit of a head protector is hard to gauge, generally at the time of buying or utilization. Snell accreditation, as measured by on-going irregular specimen testing, distinguishes those head protector models giving and keeping the largest amounts of head protection. Helmet standards are both methods for the assessment of possible headgear and functions that help in the configuration of new headgear. A free-fall drop test as in Figure 3 was employed to drop helmets onto a flat, firm, and non-yielding steel base which replicates a road surface. The drop height based of the helmet was 1.5 m, which coincides with the standard EN 1078 drop height. According to rules governed by Snell Memorial Foundation, helmets are released with a certain mass of head forms in lab test and the g forces are recorded by instruments placed inside the head form with measurement recorded below than 300 g. Most helmets that available on the market recently are designed to bear with that 300 g standard. In case of insignificant quality control malfunctions and safety factor, industrialist is determined to achieve an impact data below 250 g (Rivara, Thompson, & Thompson, 1996). Moreover, researchers in the protective helmet industry note that since most heads can take 300 g without harm, there is no reason for making a head protector that provides a softer landing than that. A developing number of specialists in the harm prevention field state that lesser wounds ought not to be overlooked. Most riders believe that the majority of today's helmets ought to be disposed of after an accident. A standard for helmet tests exists in every country. Each has its own particular principles, but the ASTM F1446-95a head protector standard is the most-utilized standard. The majority of the measures include helmets to finish lab tests where they are situated on an instrumented head structure, flipped around and dropped for a deliberate separation onto flat or hemispherical anvils. The distances differ yet generally amidst one and two meters (Mills et al., 1991). For the helmet to pass, the instruments inside the head structure must be under 300 g's amid the effect, or in some cases under 250 or even 200 g's. The three most frequently used helmet testing standards are EN1078, CPSC, ASTM F1447 and Snell B-95. Table 2 demonstrates the correlations among each standard.

Table 2: Helmet test criteria.

	CPSC	ASTM F1447	Snell B-95	EN 1078
Drop height on flat anvil (m)	2.0	2.0	2.2	1.5
Drop height on hemispherical anvil (m)	1.2	1.2	1.5	N/A
Head form weight (kg)	5	5	5	4
Failure threshold (g)	300	300	300	250

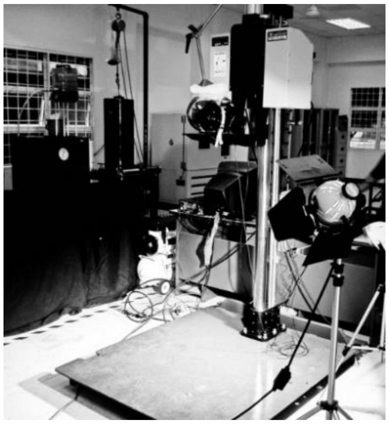


Figure 3: Oblique Impact Free Fall Test Rig.

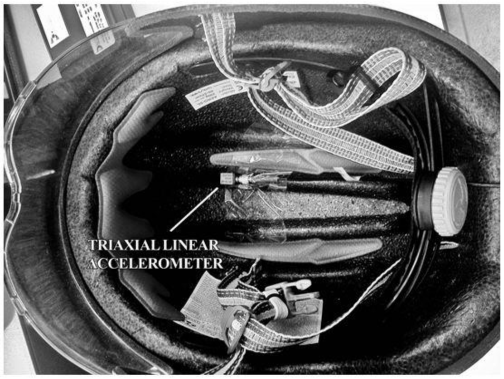


Figure 4: Tri-axial linear accelerometer placement inside the helmet.

In direct impact tests, as the motion of the headform center of gravity is approximately along a straight line, it is possible, knowing the initial impact velocity, to integrate the headform acceleration twice with respect to time.

Results

The motions of the helmets were recorded using accelerometer and high speed video camera. In each plot, the times of the three separate impacts are marked with vertical lines. The data was collected using King Design, which provides systematical and digital analysis of the dropped helmet. First the profile of the object tested and the environment was set to the King Design profile setup as shown in Figure 5. Then Figures 6 to 11 show the acceleration versus time plots at various locations on the bar using the two dropping methods for each helmet without any ballast in the headform. Table 3 gives the results for resultant linear acceleration for the three different helmets as tested according to EN1078 standards.

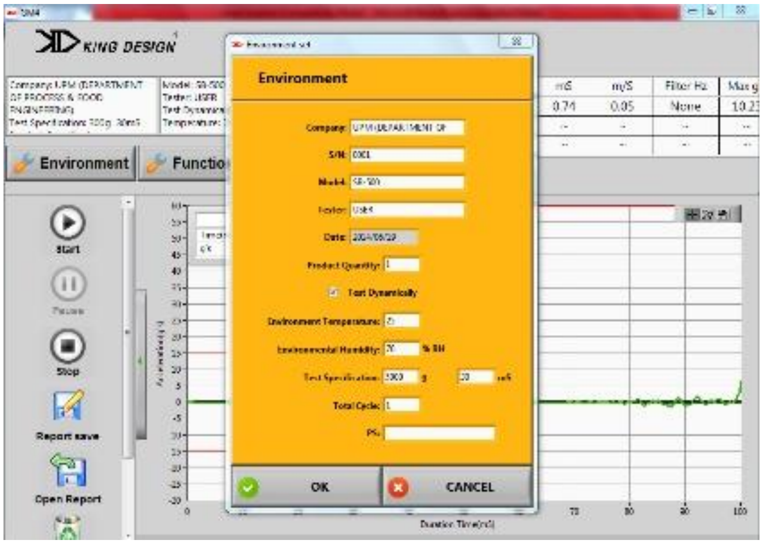


Figure 5: Environment data entry for King Design.

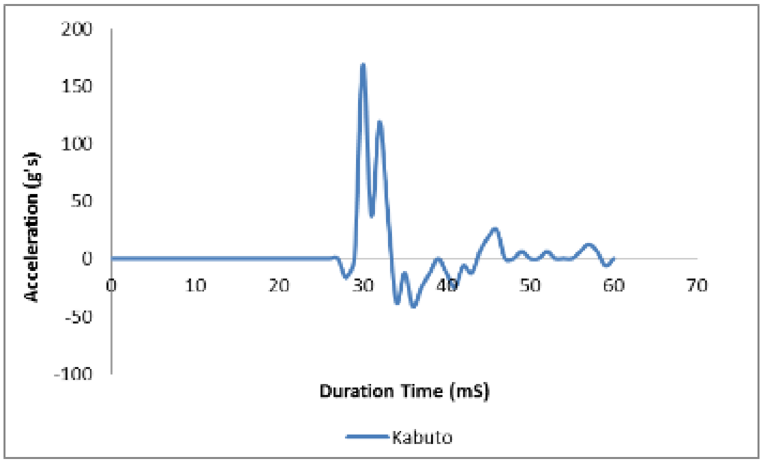


Figure 6: Accelerometer data for Kabuto Helmet.

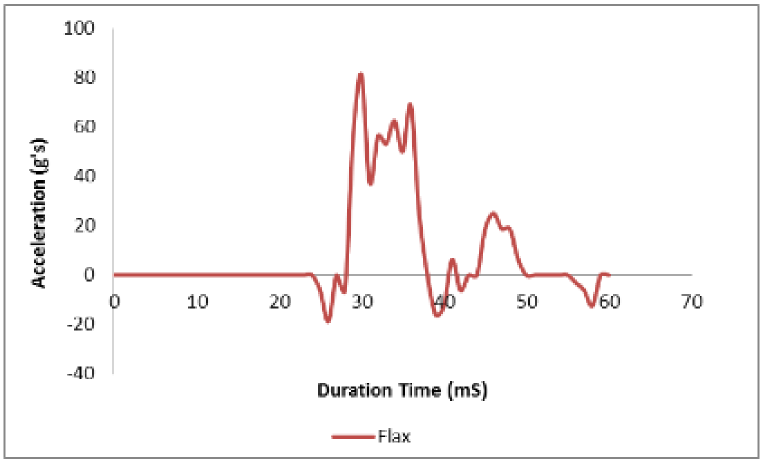


Figure 7: Accelerometer data for Flax Helmet.

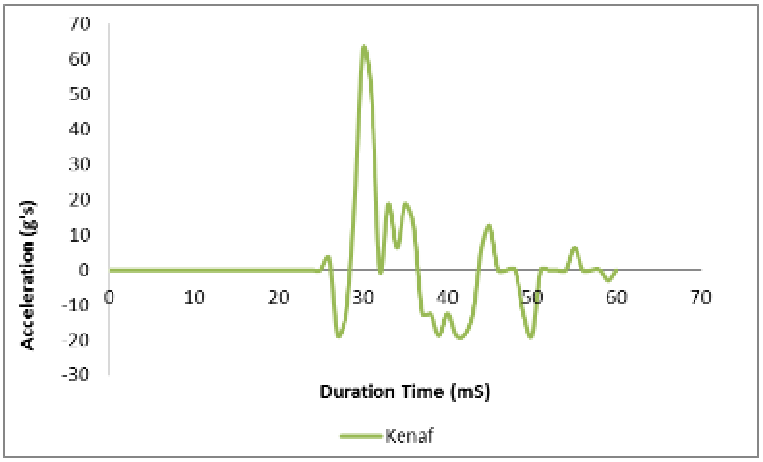


Figure 8: Accelerometer data for Kenaf Helmet.

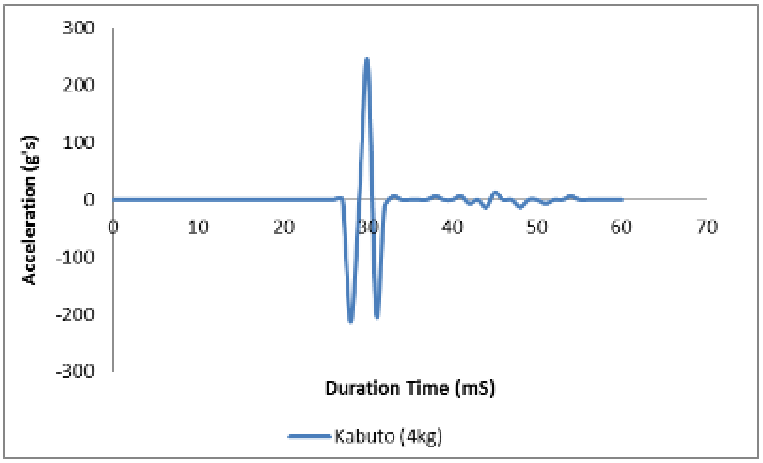


Figure 9: Accelerometer data for Kabuto with 4 kg mass (acceleration versus time plots).

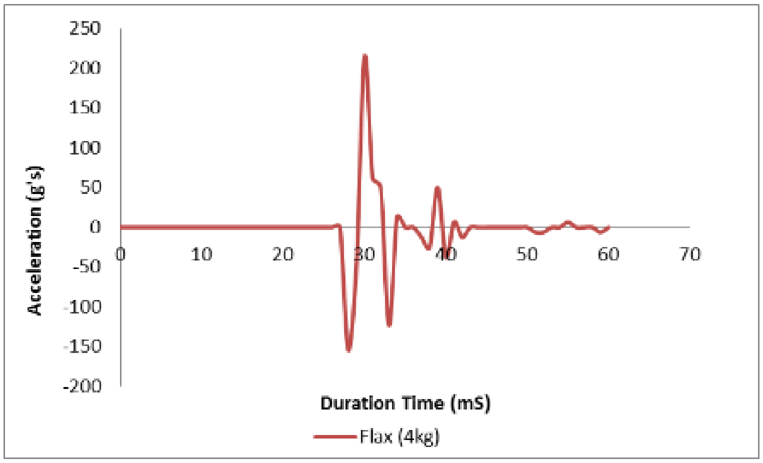


Figure 10: Accelerometer data for Flax with 4 kg mass (acceleration versus time plots).

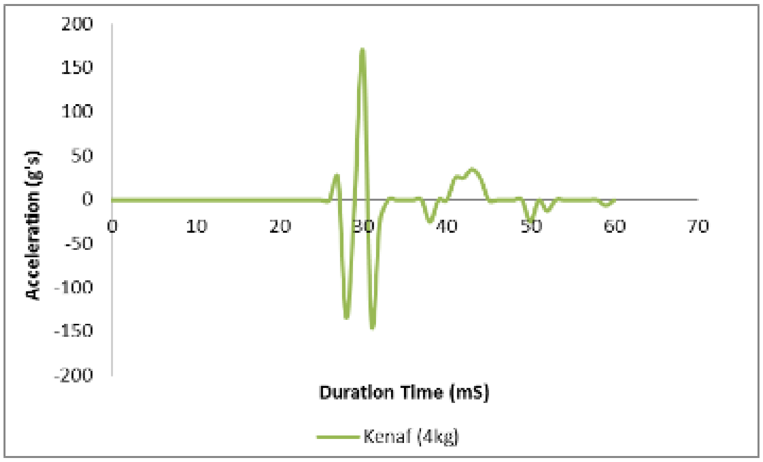


Figure 11: Accelerometer data for Kenaf with 4 kg mass (acceleration versus time plots).

Table 3: Helmet data from Tri-axial linear accelerometer.

	Max g's	Min g's
Kabuto	168.49	-41.89
Flax	81.28	-16.17
Kenaf	62.83	-18.79
Kabuto (4 kg mass)	242.88	-212.98
Flax (4 kg mass)	214.16	-122.92
Kenaf (4 kg mass)	168.48	-140.20

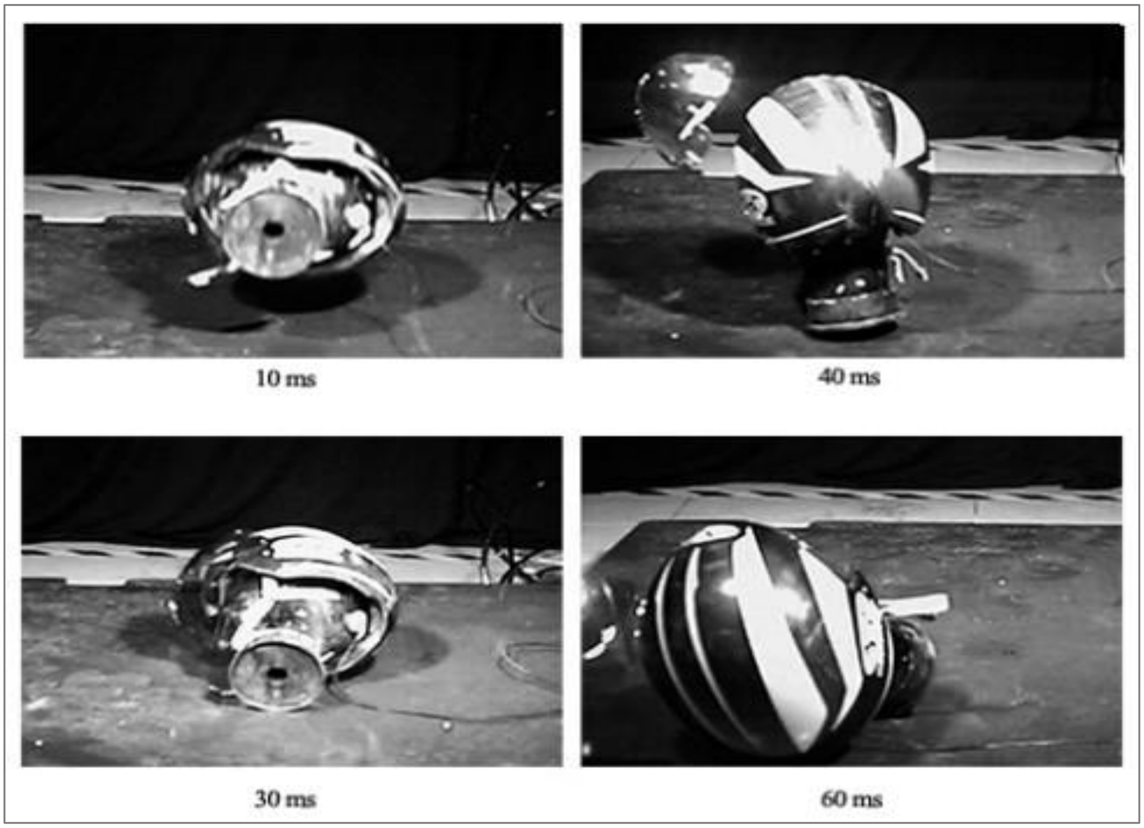


Figure 12: Frames of video of oblique impact with sequence in milliseconds for Kabuto Helmet.

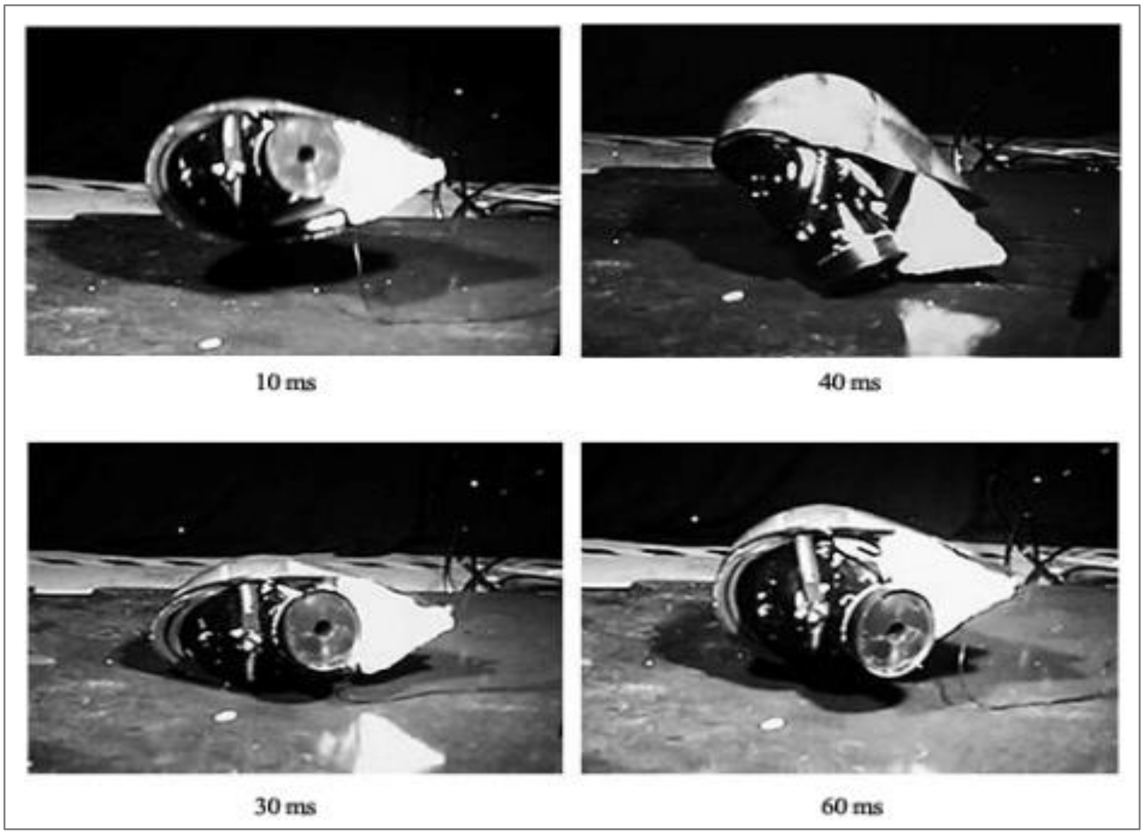


Figure 13: Frames of video of oblique impact with sequence in milliseconds for Flax Helmet.

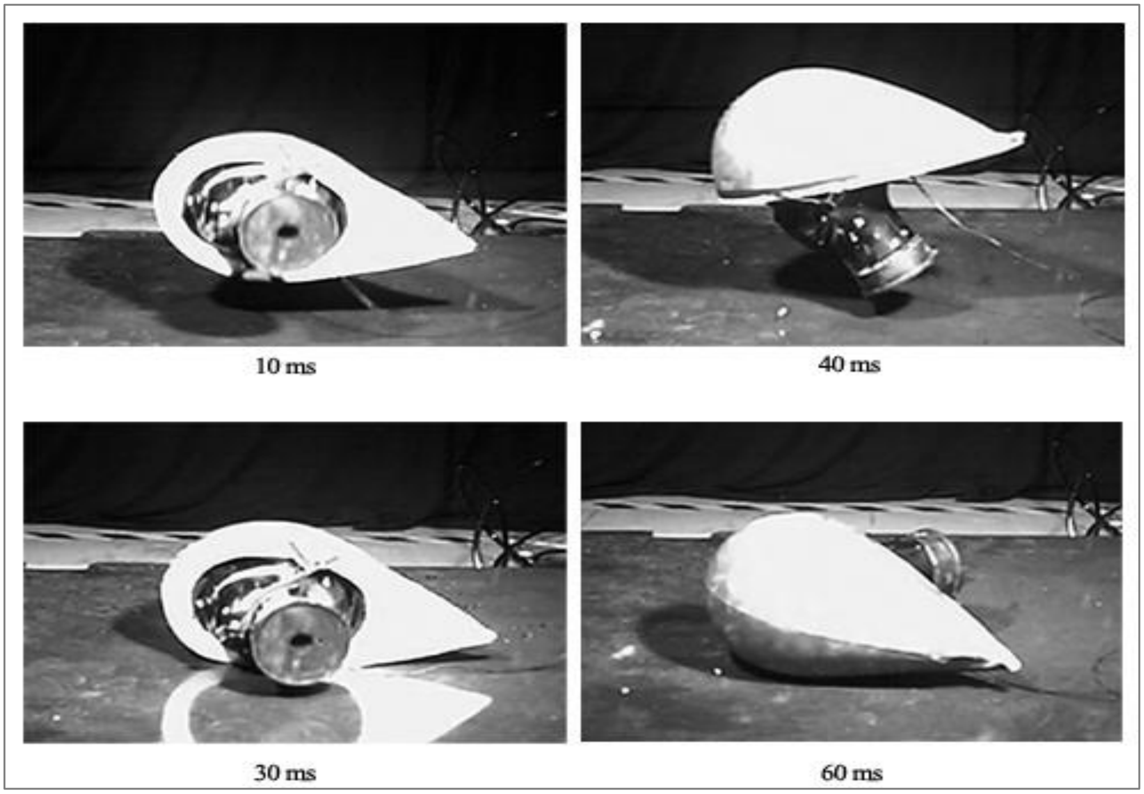


Figure 14: Frames of video of oblique impact with sequence in milliseconds for Kenaf Helmet.

Discussions

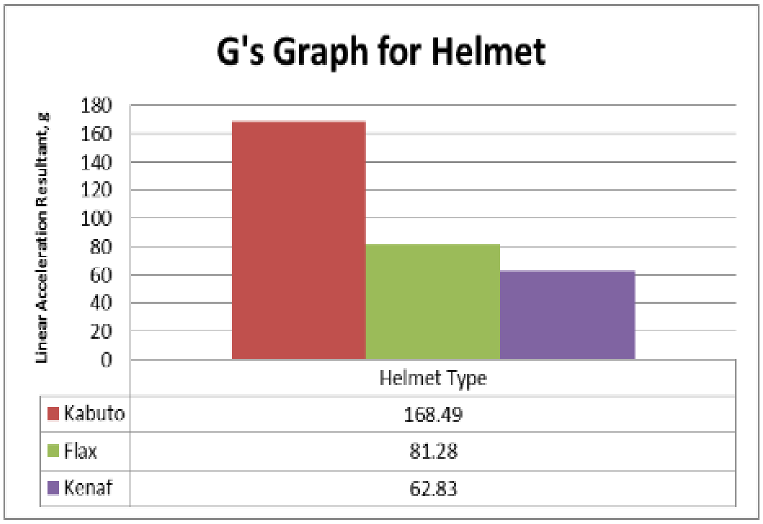


Figure 15: Gravitational Acceleration Graph without mass.

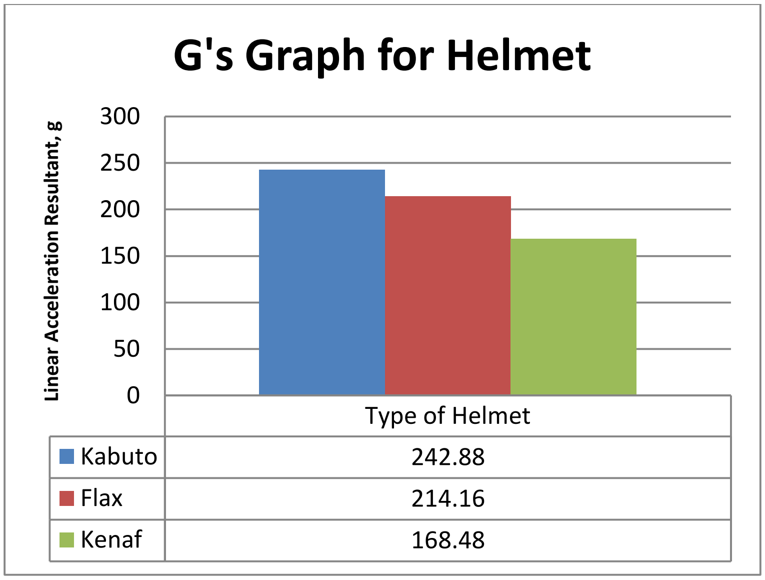


Figure 16: Gravitational Acceleration Graph with 4kg mass.

Tables 3 and 4 show the resultant linear accelerations for these three types of helmets. For Table 3 without mass, the highest linear acceleration resultant was the Kabuto helmet with 168.49g. The Flax helmet recorded 51.76% linear acceleration resultant loss with 81.28g. Meanwhile, the Kenaf helmet recorded 62.71% linear acceleration resultant loss with 62.83g from the Kabuto helmet and 22.70% linear acceleration resultant loss from the Flax helmet. For Gravitational Acceleration Graph with 3kg mass, the Kabuto helmet recorded the highest linear acceleration resultant with 242.88g and followed by the Flax helmet with 11.82% linear acceleration resultant loss with 214.16. The Kenaf helmet recorded 168.48g with 30.63% linear acceleration resultant loss from the Kabuto helmet and 21.33% linear acceleration resultant loss from the Flax helmet.

The application of conservation of energy to a falling object allows us to predict its impact velocity and kinetic energy, but we cannot predict its impact force without knowing how far it travels after impact. The test was conducted using a high speed camera for distance video analysis for the distance of the helmet after impact. As an object falls from rest, its gravitational potential energy is converted to kinetic energy. Conservation of energy as a tool permits the calculation of velocity just before it hits the surface. The dynamic energy in a moving object can be expressed as follows:

$$\text{Potential Energy, PE} = mgh \quad (1)$$

$$\text{Kinetic Energy, KE} = \frac{1}{2}mv^2 \quad (2)$$

$$\text{The impact velocity, } v = \sqrt{2gh} \quad (3)$$

"Impact force x distance traveled = change in kinetic energy"

Potential energy with respect to gravity is PE = mgh. When an object is dropped, thrown downward or projected upward, its kinetic energy becomes KE = $mv^2/2$, along with a factor of the initial velocity.

Table 4: The relationship between impact force value on the value of distance after impact and the mass of the helmet.

Types of Helmet	Impact Force	Distance after Impact	Kinetic Energy, KE	Velocity before Impact, v
Kabuto	176.876 N	0.278 m	49.172 J	5.422 m/s
Flax	177.849 N	0.274 m	48.731 J	5.422 m/s
Kenaf	171.176 N	0.287 m	49.127 J	5.422 m/s

The impact force value depends on the value of distance after impact and the mass of the helmet, as the impact force equals to change in kinetic energy divided by distance traveled. The sum of the potential energy and the kinetic energy is the total energy, which is a constant. Equating the initial total energy with the final total energy, the final velocity of the object can be determined.

Conclusion

An oblique impact test, which best replicates real-life bicycle crashes, was performed on three different helmets. To reduce the impact force of the helmet the material used for the shell of the helmet plays an important role, because the higher the absorbed energy from the impact event, the less deformation will happen to the helmet. Elastic materials are great for energy absorption as they hold energy and release it later on. Thus, a good material for helmet shell and interior for the padding of the helmet is important for absorbing energy and reducing the risk of injury to the cyclist.

Acknowledgement

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