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US Army Research Laboratory

Fabrication of Helmet Surrogate for the Walter Reed Army Institute of Research (WRAIR) Projectile Concussive Impact Model of Mild Traumatic Brain Injury

by John R Brown

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Weapons and Materials Research Directorate, ARL

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14. ABSTRACT
The Walter Reed Army Institute of Research (WRAIR) projectile concussive impact (PCI) model is designed for preclinical analysis of concussion on male adult Sprague-Dawley rats. This model represents a noninvasive, closed-head injury caused by blunt impact and is used to study mild traumatic brain injury (TBI). Materials analysis completed within the US Army Research Laboratory (ARL) was verified by WRAIR through experimental testing. Based on these results, ARL designed and fabricated composite helmets that assured that the rats in the trial were protected against injury greater than mild TBI or concussion. This technical note is a description of the rat helmet fabrication process.

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1. Introduction

A concussion is defined as a mild form of traumatic brain injury (TBI) generally resulting from a blow to the head. Mild TBI makes up about 75% of the brain injuries that occur each year. Over 230,000 service members have been diagnosed with mild TBI since 2000, which has been designated the "signature injury" on the military conflicts in the Middle East.[1,2]

Most of the preclinical research models designed to study the neurobiology of concussion are modified versions of the gold standard models of moderate/severe TBI, including the controlled cortical impact (CCI)[3] and the fluid percussion injury (FPI)[4]. To accommodate the study of mild TBI, the force of impact is simply reduced, but there is still direct impact to the cortical tissue (exposed via craniotomy). There are nonimpact models that can be used instead of these invasive techniques; however, since the majority of concussions are caused by impact, nonimpact models are not necessarily relevant. The Walter Reed Army Institute of Research (WRAIR) projectile concussive impact (PCI) model is designed to provide a truly noninvasive, closed-head model for mild TBI.[5] The WRAIR PCI testing uses male adult Sprauge-Dawley rats (280–320g; Charles River Labs, Raleigh, Virginia, USA) for experimentation. All procedures involving animal use were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of WRAIR. The research was conducted in compliance with the animal welfare act, Guide for Care and Use of Laboratory Animals (National Research Council) and other federal statutes and regulations. The animals were housed individually under a 12-h light/dark cycle in a facility accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International. Figure 1 shows the WRAIR PCI device, which consists of an elevated platform and restraints to hold the rat in place during testing, a plastic barrel that delivers the projectile, and the computer controlled pneumatic train that provides propulsion to the projectile. The inset of the figure shows a helmet protected rat before the test begins.

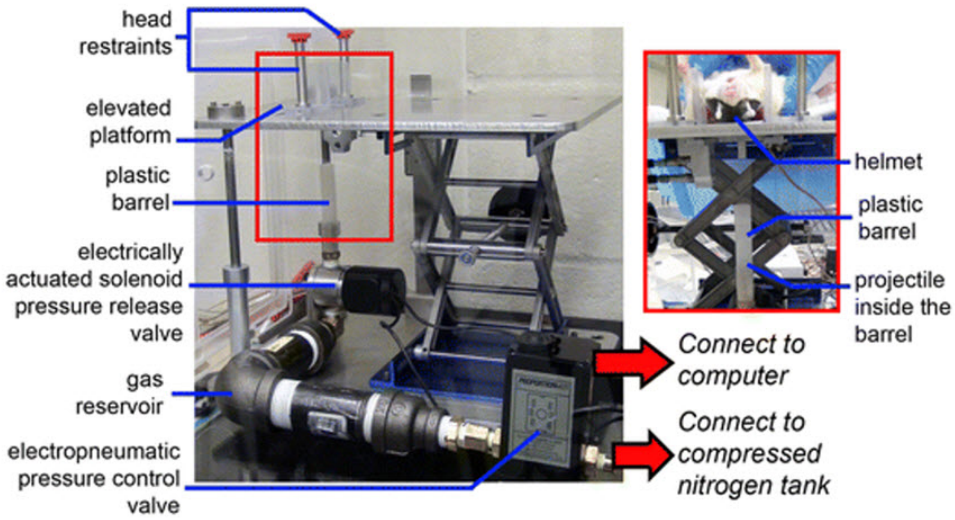

Fig. 1 WRAIR PCI device. The red inset shows a side view of the device with a helmet protected rat (laying on its back).[5]

In initial experimentation, WRAIR used a dry ice driven system where overpressure inside a sealed microcentrifuge container would build until the cap of the container popped off. The microcentrifuge cap would then become the projectile used to impact the rats. The original experimentation also used a steel spoon as the helmet to protect the rats. The cap projectile and spoon helmet proved to provide inconsistent results, and the US Army Research Laboratory (ARL) set out to create a more repeatable system for WRAIR analysis. ARL conducted impact analysis of candidate projectiles to determine the most repeatable projectile performance. This testing is shown in Fig. 2.

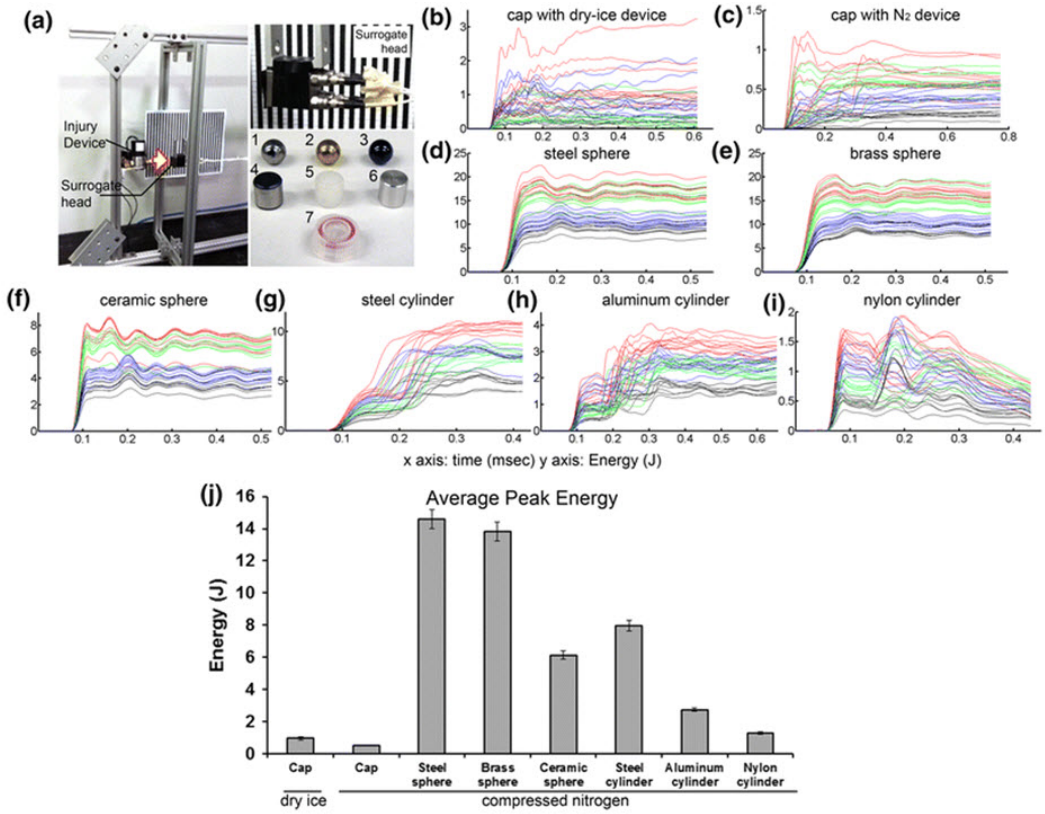

Fig. 2 Projectile analysis: (a) instrumentation including the injury device and a surrogate head with 4 accelerometers, and projectiles: 1. steel sphere, 2. brass sphere, 3. ceramic sphere, 4. steel cylinder, 5. nylon cylinder, 6. aluminum cylinder, 7. microcentrifuge cap; (b–i) impact energy profiles (energy vs. time) of each projectile. Blue, black, red, and green lines represent data obtained from each of the accelerometers (top left, top right, bottom left, and bottom right corners respectively; (j) the average peak energy of each projectile.[5]

ARL also conducted an analysis of composite material systems to determine if a composite solution would be adequate to replace the steel spoon and meet the helmet requirements. American Society for Testing and Materials (ASTM) Standard D3039_D3039M-08, "Standard Test Method for Tensile Properties of Polymer Matrix Materials" with an Instron 1125 testing machine and a 10kN load cell at a loading rate of 2 mm/min was used for initial characterization. A selection of composite samples evaluated is shown in Fig. 3.

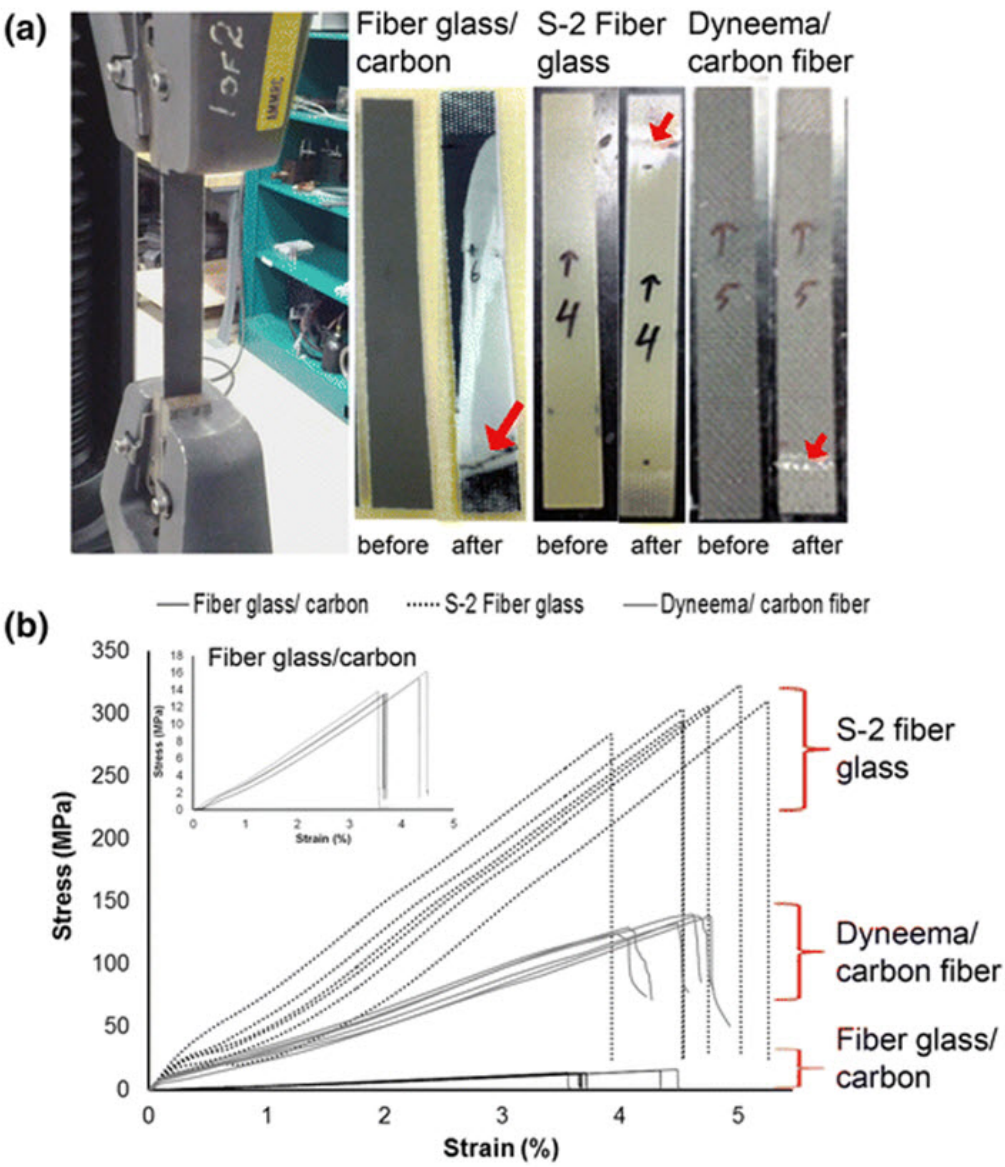

Fig. 3 Composite material tensile testing, including: (a) Instron 1125 testing machine and composite materials before and after testing (red arrow indicates fracture); (b) stress-strain curves of tested samples. Inset shows stress-strain curve of the fiber glass/carbon samples.[5]

A thorough description of the mechanical and material analysis can be found in work done by Chen et al. 2012,[5] which resulted in the selection of the glass fiber and carbon fiber composite system to be used for the rat helmets. The fiber glass used is an S-2 glass woven textile preimpregnated with an epoxy matrix for bonding (7781 fabric style with Cycom 381 resin, Cytec Industries, Inc., Havre de Grace, Maryland). The carbon fiber is a unidirectional fiber tape preimpregnated with the same epoxy matrix (IM-7 carbon tape with Cycom 381 resin, Cytec Industries, Inc,

Havre de Grace, Maryland). These helmets were fabricated using a 3-dimensional (3-D) mold of an adult Sprauge-Dawley rat (300 g; Charles River Labs, Raleigh, Virginia, USA).

2. Procedure

A 3-D scan of the aforementioned rat was performed and the resultant model was fabricated by Fused Deposition Modeling (FDM), a 3-D Printing technology. Two molds were fabricated in this manner, one mold consisting of 5 rat head sections and one mold consisting of 6 rat head sections. These molds are used to form the preimpregnated fabric and tape to the contours of the rat head, thereby creating a helmet specifically designed for this type of rat.

2.1 Material Preparation

The preimpregnated fiber textile and tape are stored in a freezer in order to prevent curing of the epoxy matrix. These materials must be removed from the freezer and allowed to thaw to room temperature (approximately 2 h depending on environmental conditions). The materials remain sealed during thaw to prevent moisture uptake. Once thawed these materials are cut into desired 2-dimensional (2-D) patterns by a computer controlled cutting table (DCS 2500, Gerber Technology Inc, Marblehead, Massachusetts). These patterns are then stored in a freezer until approximately 2 h before they are needed.

2.2 Mold Preparation

The rat head molds are placed on a steel caul plate to prevent warpage during processing. The caul plate is cleaned with acetone to make sure no contaminates will affect processing. Tack tape (GS 43MR, Coastline International, Amityville, New York) is applied to the clean, dry surface of the caul plate and “ears” are made with the tack tape to allow for the bagging material to conform over the molds without creating unnecessary voids. Figure 4 shows this step.

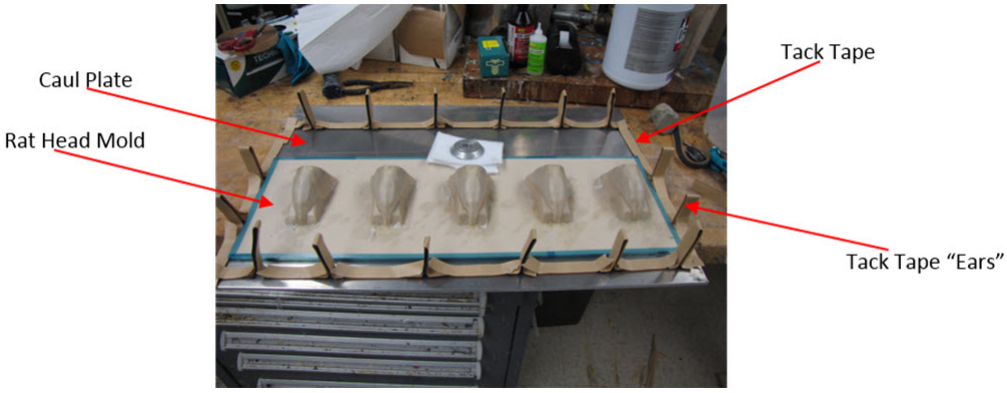

Fig. 4 Rat head mold on caul plate with tack tape and tack tape "ears" surrounding the mold

Release film (WL 5200B, Coastline International, Amityville, New York) is fitted to each of the rat heads and breather cloth is laid down around each mold. The breather cloth (Econoweave 44, Coastline International, Amityville, New York) is used to create pathways for the air to escape when the system is placed under vacuum. A vacuum port is also added with breather cloth under it (note that the breather cloth under the vacuum port must be in contact with the breather cloth around the rat heads in order to assure all air can be removed during processing). Figure 5 shows this process.

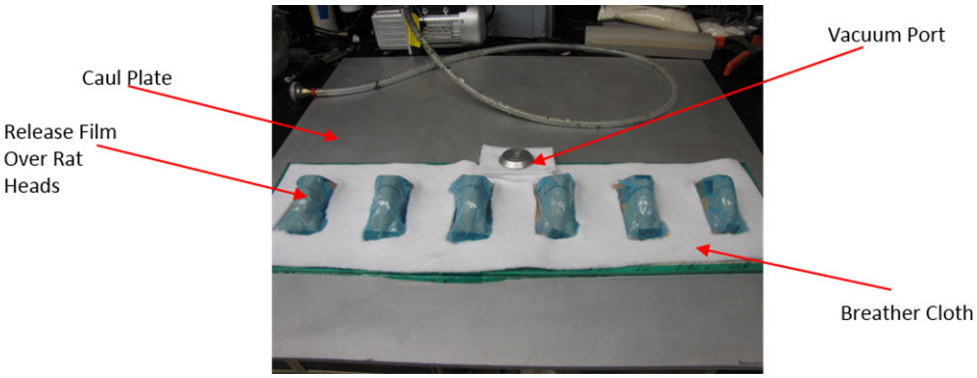

Fig. 5 Release film applied to each rat head mold. Breather cloth and vacuum port added.

2.3 Preimpregnated Material Processing

Preimpregnated materials (at room temperature) are applied in layers. The first layer (bottom most layer, in contact with the release film over the rat head mold) is S-2 glass that is placed 0.866 inches from the base of the mold as shown in Fig. 6. This measurement is taken during the placement of the initial layer to assure

repeatability. A single drop (0.05 ml) of Freekote (700 NC, ACP composites, Livermore, California) mold release is applied to the first layer of S-2 glass. This mold release is applied in a location corresponding to the impact location in which WRAIR will be testing. A template is used to place this droplet based on the area of interest. The mold release prevents the bonding of the layers in a precise location. This allows for the helmet to be protective but partially compliant in the desired location. The next layer added is carbon fiber tape. Unlike the woven fiber glass, the carbon tape only has reinforcing fibers in one direction. This layer is placed so that the fiber orientation correlates with the axial direction of the head (in line with the spine of the rat). As layers are added, wrinkles should be relaxed by massaging them out by hand. Once this layer has been put into place, another drop of Freekote is added to the desired location. The third layer is carbon tape, which is placed so that the fiber orientation is 90° from the previous layer. Once this layer has been placed, another drop of Freekote is added to the desired location. The final layer is another layer of the S-2 glass.

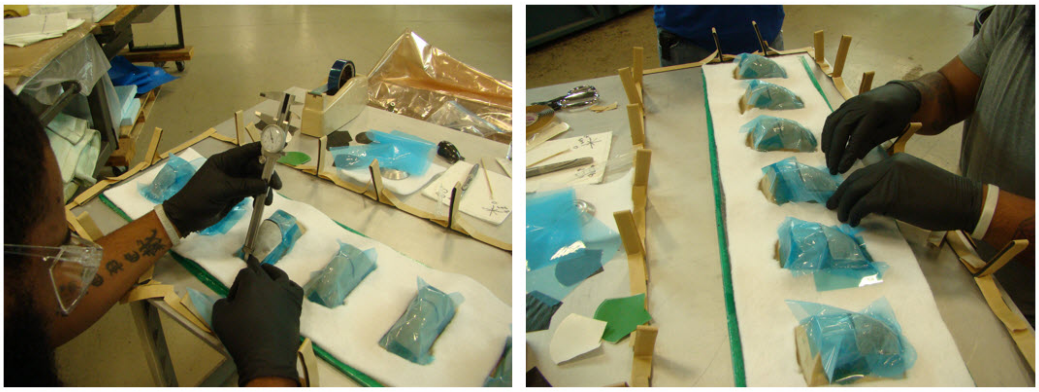

Fig. 6 Distance measurement from the base of the mold is taken to assure fiber placement is repeatable (left). Release film is applied once all layers of preimpregnated materials are placed (right).

Once all of the preimpregnated material is in place, a layer of release film is placed on top, as shown in Fig. 6.

A vacuum bag (SL 800, Coastline International, Amityville, New York) is placed on top of the mold area and is sealed down with the tack tape already on the caul plate. When sealing the bag, one should start in between 2 ears and work around the caul plate. Take any excess bag created from the ears and seal it along the length of the mold. This is shown in Fig. 7. While adhering the bag to the tape, excess bagging material is used to make sure the bag can conform to the shape of the mold when the system is placed under vacuum.

Fig. 7 A vacuum bag is placed over the mold and caul plate (left). The bag is sealed using the tack tape already applied to the caul plate (right).

A vacuum line is attached to the vacuum port via a small incision in the bag directly above the vacuum port. Once a vacuum line is attached, approximately 0.7 atmosphere of vacuum is applied in order to assure the vacuum bag can sufficiently secure the preimpregnated material to the rat head molds. During this step, spread the bag, by hand, around the vacuum port and rat head molds to assure there are no wrinkles in these areas. When wrinkles are removed, 1.0 atmosphere of vacuum is applied to the system. Care is taken to make sure that the preimpregnated materials are still in the desired location. The fully vacuumed system is shown in Fig. 8.

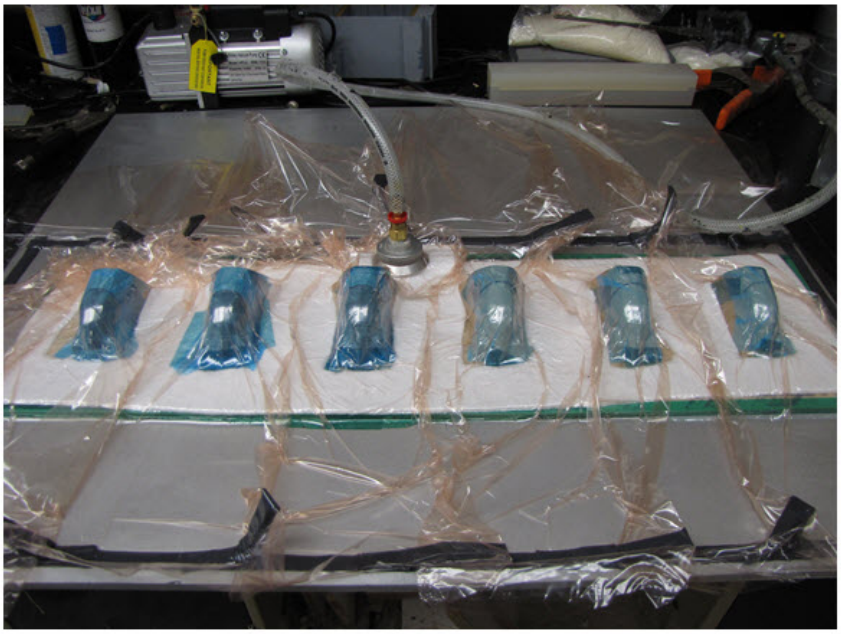

Fig. 8 Vacuum bagged system before curing of the preimpregnated materials

Once the vacuum bagging is complete, the preimpregnated materials need to be cured. For these materials, the system is heated to 250 °F and soaks at that temperature for 2 h and then allowed to return to room temperature overnight.

2.4 Postprocessing

Once the system has returned back to room temperature, the bag, release film, and breather cloth is removed. The consolidated and cured preimpregnated material is now a rigid composite and is the rough estimate of the final part. A template of the final helmet shape is used to assist in final machining. A hand grinder with a cutting blade can be used to precisely cut out the finished helmet. A rough part and finished helmet is shown in Fig. 9.

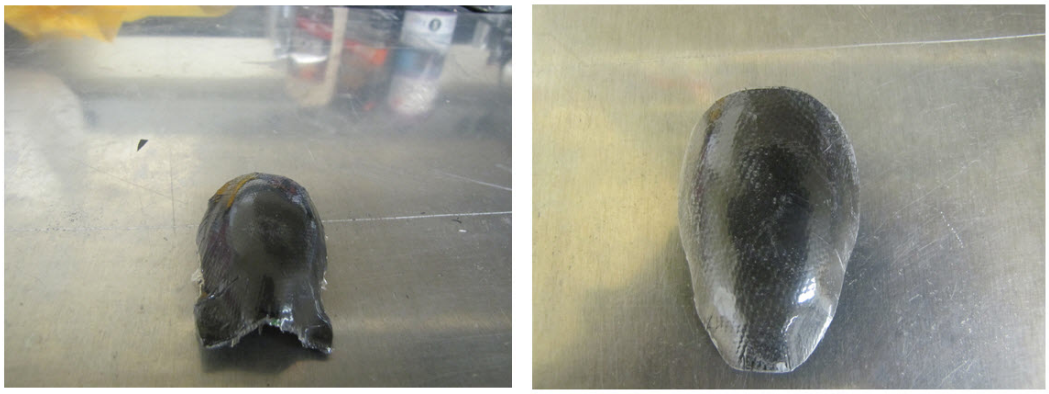

Fig. 9 The rough helmet before final machining (left) and the final helmet (right)

As described previously, WRAIR requires a section of the helmet to be more compliant than the overall structure. This is noted by the location of the drops of Freekote that are added to the preimpregnated layers, at desired locations, during processing. The final step in the fabrication of these helmets is to delaminate the section of the helmet correlating to the area where the Freekote drops have been added. A weight drop is used to strike this position to assure that each layer of the helmet delaminates from the adjoining layers.

3. Conclusions

ARL conducted material and mechanical analysis in the support of the WRAIR PCI model. This analysis showed that a new helmet system was required to allow WRAIR to collect accurate and repeatable results using their PCI device. ARL then created a process for fabricating these helmets. ARL fabricated multiple test

helmets in order to establish the validity of the process. This program has since transitioned to the Edgewood Chemical Biological Center's Advanced Design and Manufacturing (ADM) Branch for the production of hundreds of rat helmets for WRAIR research.

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List of Symbols, Abbreviations, and Acronyms

2-D	2-dimensional
3-D	3-dimensional
ADM	Advanced Design and Manufacturing
ARL	US Army Research Laboratory
ASTM	American Society for Testing and Materials
CCI	controlled cortical impact
FDM	Fused Deposition Modeling
FPI	fluid percussion injury
IACUC	Institutional Animal Care and Use Committee
PCI	projectile concussive impact
TBI	traumatic brain injury
WRAIR	Walter Reed Army Institute of Research

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