APPLICATION BRIEF

Bullet Impact on a Ballistic Helmet

Today, military forces are protecting their troops using helmets that are designed with lightweight composite fiber materials. As an alternative to developing and testing prototypes, simulation using ANSYS® AUTODYN® software is used to examine the impact of a 9 millimeter full metal jacket projectile on a composite helmet, to assess damage to the helmet, and to observe deformation of the projectile in order to provide clues as to how to defeat and mitigate such threats.

Helmets have a long history, and their use may be as old as warfare itself. In the Battle of Thermopylae, in 480 BC, the Spartans donned helmets crafted from bronze. These single-piece helmets provided complete head protection and had narrow slits in the front for vision and ventilation. Later in first century AD, Roman gladiators who fought in the Colosseum protected their heads, faces and necks with helmets designed with broad brims and pierced visors. This proliferated use of helmets as a form of head protection in combat lasted until the American Civil War. Although helmets experienced a reprieve in the Civil War, they were reintroduced in World War I. In World War I and World War II, helmets were made of steel. During these periods helmets were crafted from a steel shell and fitted with an inner liner. The Stahlhelm used by the Germans in World War I and the M1-Helmet used by the Americans in World War II are examples of steel-crafted helmets.

Recent wars have demonstrated the importance of helmets in reducing head wounds. Reports reveal that although the head and neck of a soldier represent 12 percent of the body area, they receive up to 25 percent of all "hits" during combat. These surveys indicate that most soldiers do not like helmets because they are heavy and get in the way. This information has led military forces to turn away from steel to lighter materials for helmet design.

Figure 1. ANSYS AUTODYN model of a human head and ballistic helmet

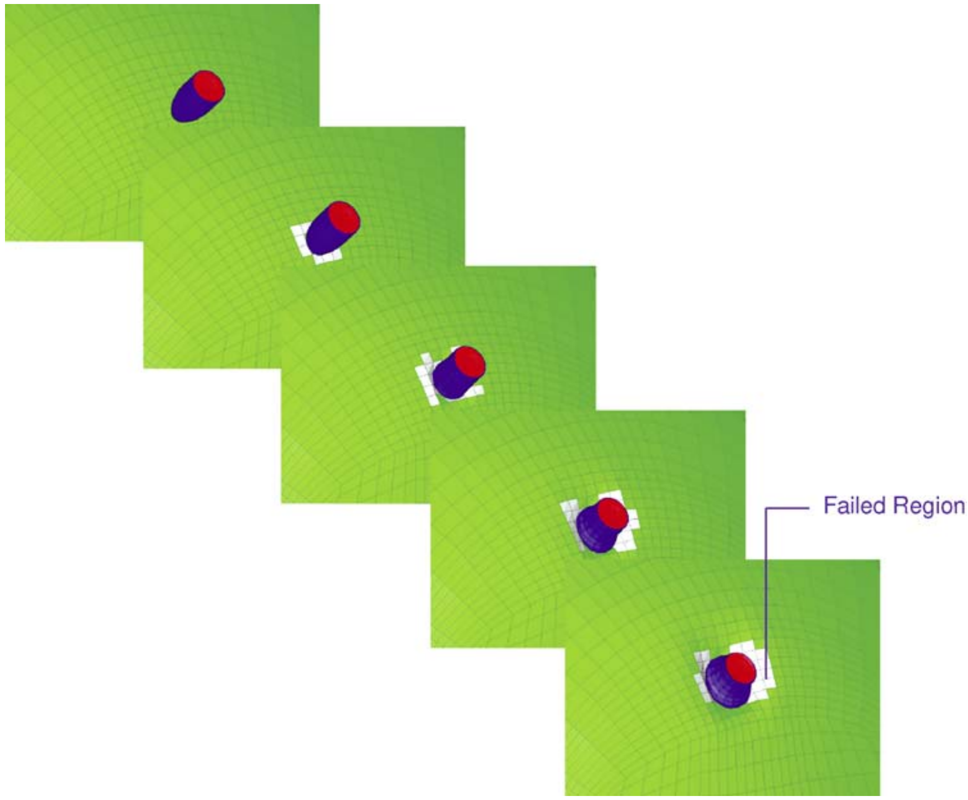

Figure 2. Projectile impact, showing the deformation of both the outer surface of the helmet and the projectile itself

Today, military forces are protecting their troops with helmets designed using lightweight composite fiber materials. The PASGT (United States), MICH (United States), MK-6 (United Kingdom) and SPECTRA (Denmark) helmets are examples of designs that use lightweight fiber materials. The ongoing development of lighter and stronger fiber materials — para-aramid (KEVLAR®, Twaron®), UHMW polyethylene (Spectra®, Dyneema®) and PBO (Zylon®) — has persuaded defense agencies to agree that the next generation of combat helmets should be lightweight and yet provide superior protection.

In the development of the next generation of combat helmets, research agencies and defense contractors subject prototype helmets to a series of ballistic tests to ensure that these new designs provide adequate protection. The ballistic tests involve accelerating a projectile against a helmet and determining whether the helmet is able to defeat the incoming projectile. The process of creating a prototype helmet and striking it with a projectile can be expensive when exploring fiber materials and design variations. Hydrocode simulations can reduce the cost of development.

By creating helmet simulation models, engineers perform virtual scenario analyses. In these scenario analyses, engineers subject the helmet models to various threats and then analyze their responses and vulnerability to these threats. The results from these analyses allow the engineers to make informed decisions on the approach and to strategize to mitigate these threats.

This article demonstrates the response of a ballistic helmet to a probable threat — an accelerating 9 millimeter full metal jacket (FMJ). The 9 millimeter FMJ, which weighs approximately 8 grams, is the quintessential ammunition for handguns and pistols. The simulated projectile, which consists of a brass jacket encapsulating a lead core, strikes the side of the simulated composite helmet model at 358 meters per second. The simulation is carried out using ANSYS AUTODYN software, a commercial hydrocode.

A hydrocode is a computer program that is capable of computing strains, stresses, velocities and propagation of shock waves as a function of space and time. In the last three decades, hydrocodes have been used extensively to simulate the penetration and perforation of isotropic materials (i.e., steel and aluminum) when subjected to high velocity and hypervelocity impacts.

With the development of lighter and stronger fiber materials (i.e., KEVLAR®, Twaron®, Spectra® and Dyneema®), the scientific community expresses a growing interest in the use of hydrocode to study ballistic impact of anisotropic materials in the development of composite armor. Unlike the ballistic response of isotropic materials such as steel or aluminum, the ballistic response of anisotropic material is more complex and requires extensive material characterization.

In a project with the European Space Agency (ESA), the developers of ANSYS AUTODYN implemented a composite material model that could couple anisotropic constituent behavior with nonlinear shock response. The composite material model in ANSYS AUTODYN takes into account the following complex phenomena related to high velocity and hypervelocity of anisotropic materials: anisotropic strength degradation; material anisotropy; melting, vaporization and decomposition; shock response; and coupling of volumetric and deviatoric response.

The simulation results for the helmet reveal that though the projectile does not perforate the helmet, it possesses sufficient momentum and kinetic energy to deform the wall of the helmet. Figure 2 shows the helmet before, during, and after impact. The transient results from the simulation, depicted in Figure 3, reveal that the impact region, both on the outside and inside of the helmet, deforms with a high velocity. This high velocity along the thickness of the helmet can cause delamination.

The delamination of the composite layers often results in a backplane signature which may exceed the optimal standoff (i.e., the distance separating the head and the inner surface of the helmet), causing impact to the head along with brain trauma. Figure 4 shows the deformation that occurs on the inner surface of the helmet as the projectile impacts the outer surface. Such instances explain how a helmet may defeat an incoming projectile, and yet the soldier donning the helmet may experience brain injury. The simulation results indicate failure in the fibers at the impact region and the inside the helmet. Fortunately, the deformation and the fiber failure are not substantial enough to compromise the optimal standoff and the safety of the soldier using the helmet in this scenario.

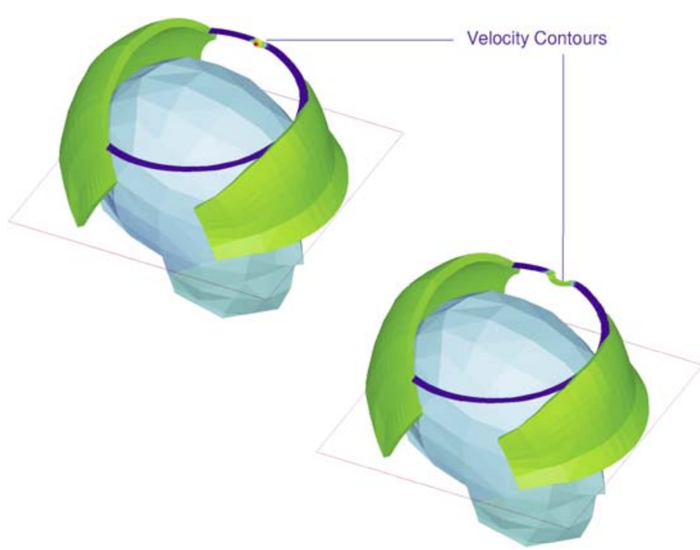

Figure 3. Velocity contours for the helmet body as impact from the projectile occurs

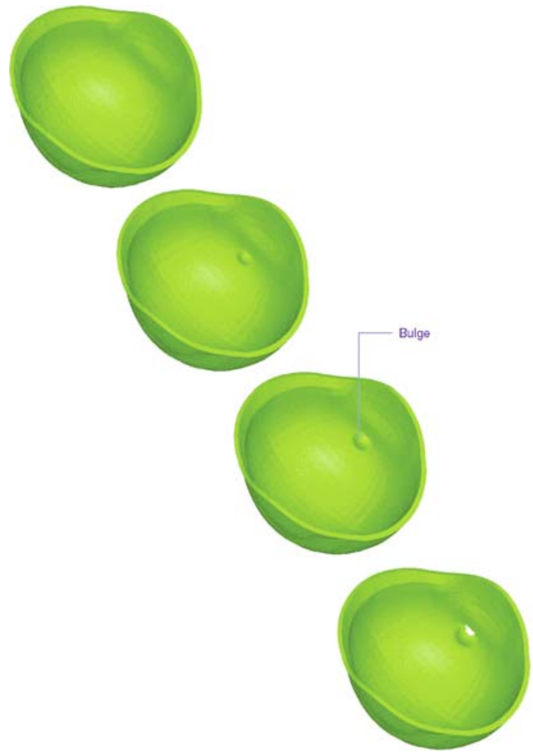

Figure 4. Deformation of the inner surface of the helmet as the projectile impacts the outer surface

The simulation also predicts the deformation of the 9 millimeter FMJ (seen in Figure 2). Accurate prediction of the deformation of the projectile can provide clues and answers to engineers seeking to defeat and mitigate such threat. In this scenario, the 9 millimeter FMJ suffers severe deformation on impact and later collapses, which reduces its effectiveness in perforating and penetrating the helmet.

In conclusion, this article has demonstrated the application of the composite material model in ANSYS AUTODYN software for predicting the ballistic response of a composite helmet. This technology is now available for ballisticians seeking to develop composite helmet and armor for future combat systems. Hence, the demonstration should inspire and motivate engineers to complement ballistic tests with hydrocode simulation in order to reduce the cost of developing the next generation of combat helmets.

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