TG-7 Ballistic Vest Supplemental Pad
White Paper

T3 Motion, Inc. develops and markets polymer materials and products that can be engineered to manage energy by dissipating, transferring, or attenuating blunt force trauma, shock, g-force loading, and vibration. T3 Motion works with a range of proprietary polymers to reduce injury and dramatically increase comfort for applications where protection to the body is critical, such as in military/police combat situations, hazardous work environments, contact sports, and medical applications.

Applications include the recent introduction of blunt force trauma pads used in conjunction with bullet proof vests to reduce back face deformation upon a ballistic impact. The product is designed for law enforcement officers, first responders and the military.

Background
TG-7 padding is comprised of a viscoelastic polymer compound typically encapsulated in a flexible polymer film of various configurations and derives its superior energy absorbing behavior from the unique physical properties of the viscoelastic compound. The bulk of the compound is composed of a high molecular weight, highly viscous, highly elastic polymer fluid. The fluid is then compounded with rheological modifiers and other fillers to control the physical and rheological properties of the finished padding compound.

T3 Motion, Inc.
970 Challenger Street, Brea, CA 92821 U.S.A.
(714) 255-0200 • www.t3motion.com • sales@t3motion.com

When any material is impacted, some of the kinetic energy of the strike is converted to heat energy. This is the *only* absorbed energy in the system. The striking force per unit area is reduced by the amount of absorbed energy and the ability of the material to distribute the load over a larger area. The polymer used in TG-7 components is ideally suited to maximize both of these attributes.

TG-7 polymer can convert more kinetic energy to heat than virtually any other materials because of its fluid properties. It is unique in regard to the fact that even at extremely high molecular weight, or very long molecular chain length, it remains a fluid at room temperature. This allows for a high amount of molecular mobility and many points of molecular contact. Upon impact the polymer chains try to flow but are impeded by the length and number of the other polymer chains they are in contact with. At each of these contact points, some of the impacting energy is converted to heat through friction. An impact's kinetic energy is dissipated over a large area due to the fluid structure and the entanglement of all of the polymer chains in the mass. In contrast, with a foam or rubber the frictional heat generated is isolated near the impact point and any impact reduction is due largely to physical crushing of the macroscopic structure.

A way to visualize the time dependent properties of the polymer compound is with oscillatory experiments. A rotational rheometer is used to apply a stress to the sample at increasing frequency. For a rigid elastic solid, the strain response to an oscillating applied stress is in phase with the stress. For a viscous fluid, the strain response to an oscillating applied stress is 90_o out of phase with the stress. For a viscoelastic material, the response is coupled with a portion in phase and a portion out of phase. We measure the phase angle response, applied stress, and resulting strain and calculate the Complex Dynamic Modulus G.

Where:

$G = G' + iG''$

Where:
i = *sqrt* (− 1); *G*' is the *storage modulus* and *G*'' is the *loss modulus*:

$$G' = \frac{\sigma_0}{\varepsilon_0} \cos \delta$$

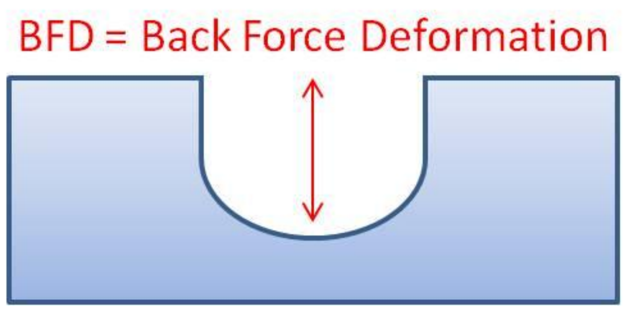
TG-7 material is in fact viscoelastic – exhibiting both elastic (G') and viscous (G") responses to applied stress. At low frequency the material is dominated by the viscous response (G"). This can be seen by pressing a finger into the material. A constant pressing is a low frequency event and a finger will push through the media as easily as if it was any other high viscosity fluid. It is this property that allows TG-7 padding to readily conform to any shape. However, at higher frequencies the material is dominated by the elastic (G') response. This can easily be seen by dropping the media on the floor. The impact with the floor happens over a very short time (high frequency) and the material will bounce like a rubber ball. Unlike rubber, the material still has a high degree of viscous response as well, and is the mechanism that makes these materials highly effective as padding.

Temperature has an effect on the physical properties of the polymer compound as it will decrease in apparent viscosity at higher temperatures, however, the decrease in viscosity does not greatly affect the impact efficacy of the material. Even a standard TG-7 polymer compound still has a high enough viscosity to dissipate impact energy at elevated temperatures. Testing of the material for use as a ballistic trauma pad (inserting a pad behind a bulletproof vest and shooting into it) showed no measurable difference over a temperature range of 20 – 35°C. The compound is remarkably stable over a large range of temperatures and will not freeze above -100°C. Additionally, compounds can be formulated to accommodate any working environment. Standard TG-7 grey will perform consistently in temperatures ranging between -20° C and 100° C.

TG-7 material compounds can as well be engineered to different specifications. An experimental compound was made into a pad that was half as thick as the 0.6 in. standard TG-7 pad, and still reduced impact force by a comparable amount. By manipulating the rheological properties of the polymers, compounds can be readily tailored to optimize results for a given application. Applications as diverse as high frequency vibration damping to blunt force energy mitigation can be addressed. Rheological modifiers and other fillers can have profound effects on the physical properties without sacrificing performance.
Because TG-7 polymers are fluids, albeit typically highly viscous fluids, they must be contained to avoid unwanted flow. TG-7 has developed encapsulation techniques and manufacturing processes that indeed contain the polymer yet still permit conformability to the subject or device to be protected while providing the desired energy absorption.

Ballistic Trauma Reduction

The blunt trauma or back face signature/back face deformation (BFD) is the amount of rearward deformation the body armor will receive when struck abruptly by a projectile (bullet). Although the bullet may not penetrate the soft body armor, the part of the body directly behind the point of impact usually receives a "hammer-like" blow as a result of the deformation of the armor from the impact of the bullet, as its velocity and energy are dissipated. This blow can produce not only bruises and lacerations to the surface of the skin, but can produce damage to internal organs.



Current methods of testing body armor include use of plastiline clay physical models. According to the U.S. National Institute of Justice (NIJ) ballistic standard 0101.06 for the testing of body armor, a flat 10.2 cm (4.0 inch) deep layer of clay is placed behind soft personnel protective armor and shot with different munitions. The depth of deformation of the clay is then measured and, for the armor to pass the test, must be less than 44 mm.

Even if a personal armor product may pass NIJ specification, if the allowable blunt trauma is located in a sensitive body area, significant injury or temporary incapacitation may result. There is a growing concern to not only provide reduction in BFD for product acceptance to the NIJ standard but also to reduce the trauma further for practical reduction in injury or the allowing of the subject to appropriately defend themselves or escape further attack.
Tests according to NIJ standards were performed on a TG-7 pad to determine its ability for BFD reduction.

First as a baseline, 9mm rounds from a distance of 6 feet (1.83 m) were shot into a typical Level IIIA vest panel placed in front of a plastiline clay target and the subsequent backface deformation produced in the clay was measured.

Subsequently, a typical TG-7 pad of 0.3 inch thickness was placed directly between the back of the Level IIIA vest section and the clay target and the ballistic tests were repeated.

The recorded test results are shown in the following report:

Ballistic Test

Test Date: June 25, 2015
Location: Palm Bay Police Department Firing Range
Palm Bay, FL 32907 U.S.A.
Agencies: Palm Bay PD/Sebastian PD/Melbourne PD

Temperature	102 F/38.8 C
Humidity	42%
Barometric Pressure	29.93
Distance	6 feet/1.83 m

Level IIIA **Back Force Deformation**

Bulletproof Vest	Ammunition	No TG-7 Pad	1 TG-7 Pad	2 TG-7 Pads
Gator Hawk	9mm Ball	24.34 mm	8.95 mm	.96 mm
			63% reduction	96% reduction
Gator Hawk	9mm Hollow Point	17.14 mm	5.9 mm	4.7 mm
			66% reduction	73% reduction
Point Blank HiLite	10 mm	23.95 mm	13.44 mm	6.07 mm
			44% reduction	75% reduction
Point Blank HiLite	40 cal	28.36 mm	9.03 mm	3.92 mm
			68% reduction	86% reduction
Point Blank HiLite	45 cal	37.91 mm	22.11 mm	15.89 mm
			42% reduction	58% reduction

Experiments in the 1970's using laboratory animals demonstrated that even when soft body armor prevents a puncture wound the liver, heart, spleen and spinal cord are still vulnerable to severe injuries known as Behind Armor Blunt Trauma (BABT).[1] Other studies have used high-speed photography to show that when impacted by a bullet the body acts as a highly damped or "viscous" system. When a bulletproof vest successfully stops a bullet, the human torso behind the vest exhibits viscoelastic behavior that includes the propagation of several types of BABT inducing waves, including:

1) stress waves--longitudinal pressure waves that travel at or slightly faster than the velocity of sound in tissue;

2) shock waves--waves of high pressure characterized by an effectively instantaneous wavefront propagated through underlying tissue at a velocity faster than the velocity of sound in tissue; and

3) shear waves--transverse waves of long duration and relatively low velocities that produce gross distortions of tissue and organs.

The modes by which the above bullet-induced waves and forces damage bones, organs and tissue are very complex. For example, stress and shear waves account for many injuries distant from the blunt impact. Stress waves in tissue may result in very high local forces producing small but very rapid distortions. Such rapid distortions usually do not result in gross lacerations to tissue; rather their effects are largely concentrated at the microvascular level to produce extravasations of blood. Shear waves may produce marked distortion of internal organs adjacent to the body wall that results in contusions or lacerations.

Because TG-7 polymer materials are viscoelastic and have proven energy dissipation over a wide frequency range there are hypotheses that the materials may be capable of

absorbing or dissipating some amount of BABT induced waves. There has not been, however, any testing done to verify or refute the hypotheses. It would be prudent at some point to perform such testing to determine the extent of TG-7 material performance with regard to BABT induced wave reduction.

1 Carroll, A. W. and Soderstrom, C.A., "A New Nonpenetrating Ballistic Injury", Ann. Surg., 188, 6, pp753-757 (1978).

For further information:

T3 Motion, Inc.
970 Challenger Street
Brea, CA 92821 U.S.A.
(714) 255-0200
sales@t3motion.com
https://www.t3motion.com/tg-7-ballistic-vest-inserts