Thermally Initiated Material Transformation in Ballistic Projectiles

PURDUE MATERIALS ENGINEERING

2015 Burton D. Morgan Business Plan Competition
2nd Place Undergraduate Division

PURDUE UNIVERSITY Discovery Park

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The MSE Ballistics senior design project is unique in that the scope of the project encompasses an entrepreneurial component. Designing a projectile that renders itself non-lethal, creating a business plan around this product, and competing in the Burton D. Morgan Business Competition were the main goals of the team. The team placed second in this competition. The current design encompasses a thermally activated material degradation of the bullet. Microscopy and thermal analysis were completed in order to determine an ideal sample composition.

This work is sponsored by Contour Hardening, Inc., Indianapolis, IN

Contour Hardening, Inc.

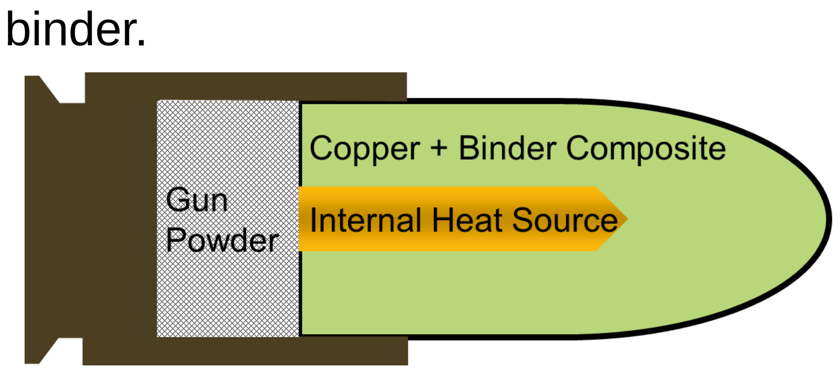
Project Background

There is a need in the law enforcement, military, and civilian sectors for a safer bullet that will significantly reduce harm to unintended bystanders. Bullets retain a significant portion of their energy after traveling hundreds or even thousands of meters. The team utilized a materials solution to render a bullet non-lethal after traveling beyond its designed accuracy range.

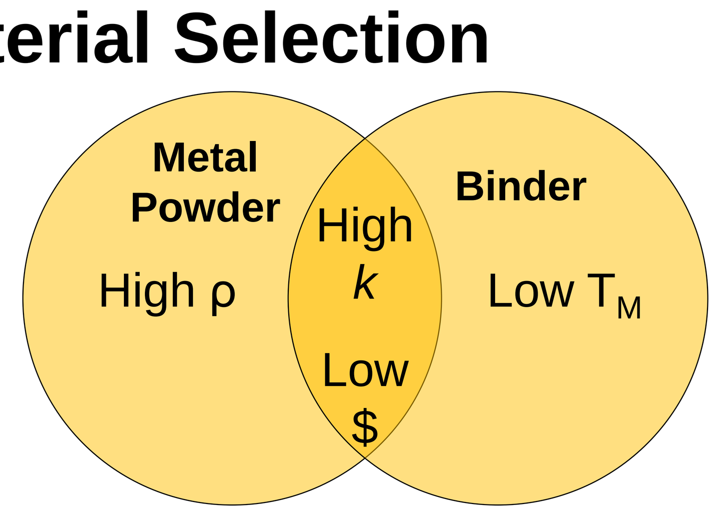
Caliber	Mass (g)	Muzzle Velocity (m/s)	Muzzle Energy (J)	Terminal Range (m)	Terminal Velocity (m/s)	Terminal Impact Energy (J)
.22 LR	3	370	140	1830	90	12
9mm Luger	8	360	520	2200	110	48
.45 ACP	15	270	560	1650	100	75

Ballistic Design

The material solution is a thermally activated degradation of the projectile over a controlled period of time. The design includes an internal heat source, metal particulates, and a low melting point binder.



Material Selection

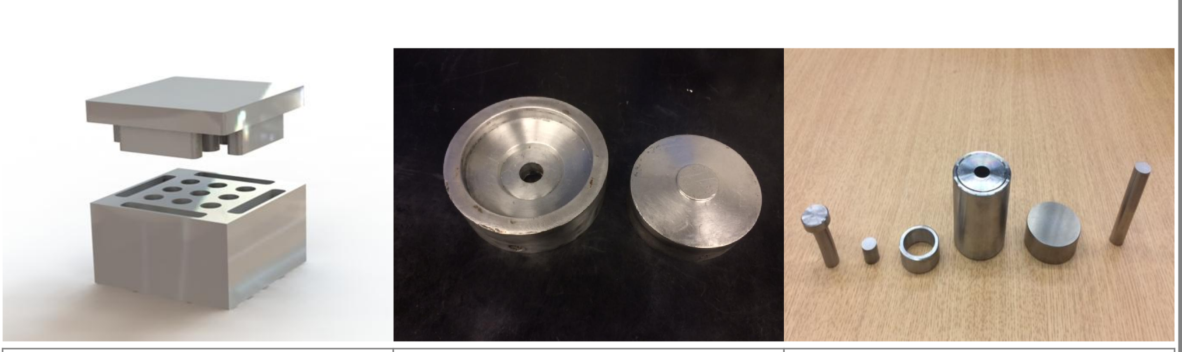


ρ = density, k = thermal conductivity, T_M = melting temperature, $ = USD

Processing

Fine Copper powder (105 µm) and polylactic acid (PLA) (T_M=160°C) were mixed at five different ratios. The mixture was hot pressed at 400°F for 15 minutes at a pressure of 10,000 psi. Three molds were used to produce samples.

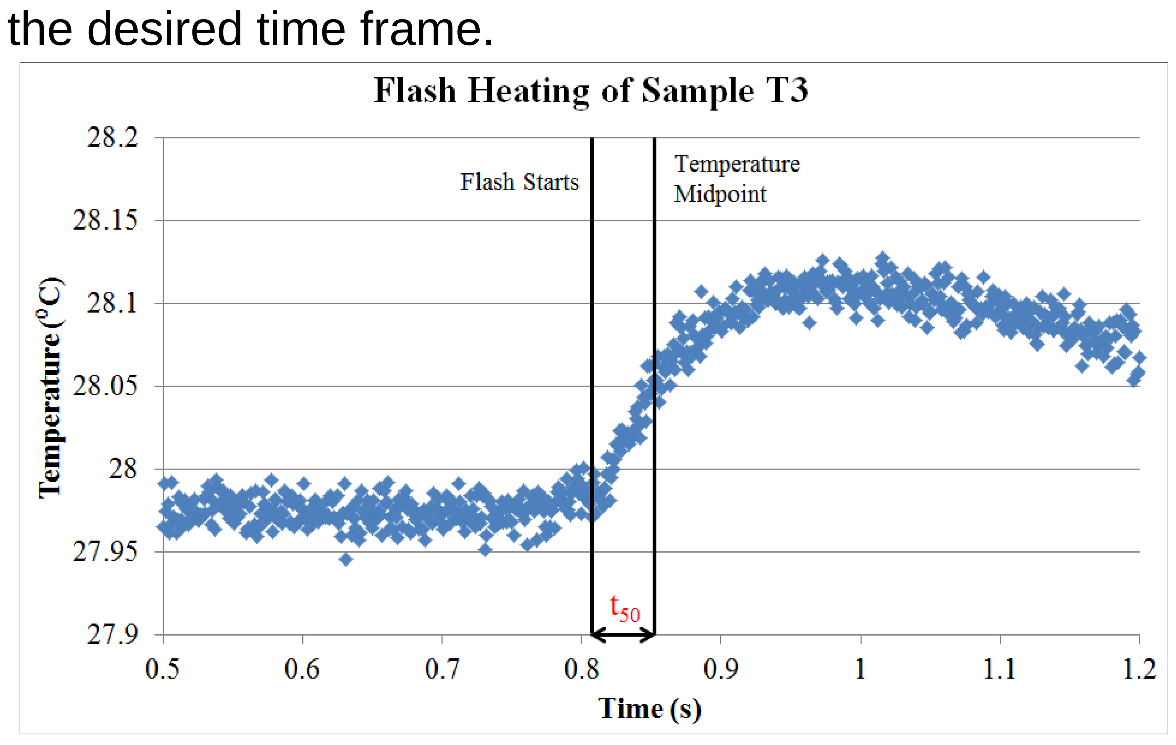
The images above show samples made using the saucer mold. The PLA to copper ratios are as follows: a) 1:0.55, b) 1:2, c) 1:3, d) 1:4, e) 1:10.



In-House Mold	MSE Saucer Mold	Pre-made MTI Mold
Pros •Customizable design •Low cost Cons •Long lead time •Room for manufacturing error •Difficult removal of samples	Pros •Low cost •Easy removal of samples Cons •Curved disc shapes •Rough surface finish •Wrong shape	Pros •Smooth surface finish •High tolerances •In stock Cons •High cost ($250 per die)

Thermal Analysis

Thermal diffusivity can be experimentally measured using the flash heating method, shown to the right. Thermocouples gather data points of temperature over the desired time frame.



The important parameter measured is t_{50}, defined as half of the time that it takes the top of the sample to reach a steady temperature after the flash. The thermal diffusivity (α) can then be found using the Parker expression, shown in equation 1, where h is the height of the sample. From there, the thermal conductivity (k) can be calculated using density (ρ) and specific heat capacity (c_p), as in equation 2.

$$\text{Equation 1: } \alpha = 0.1388 * h^2/t_{50}$$

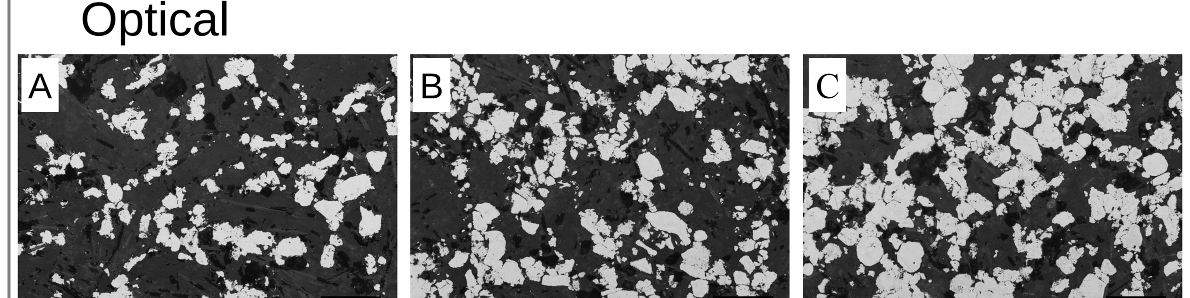
$$\text{Equation 2: } k = \alpha * \rho * c_p$$

PLA:Cu (by mass)	Density (kg/m³)	Thermal Diffusivity (mm²/s)	Thermal Conductivity (W/mK)
1:1	2540	8.9	16.5
1:1.5	2910	20.5	40.4
1:2	3350	48.3	99.7

The thermal conductivity increases dramatically as the copper content is increased. By changing the composition of the bullet, the disintegration time and the effective range of the bullet can be changed.

Microscopy

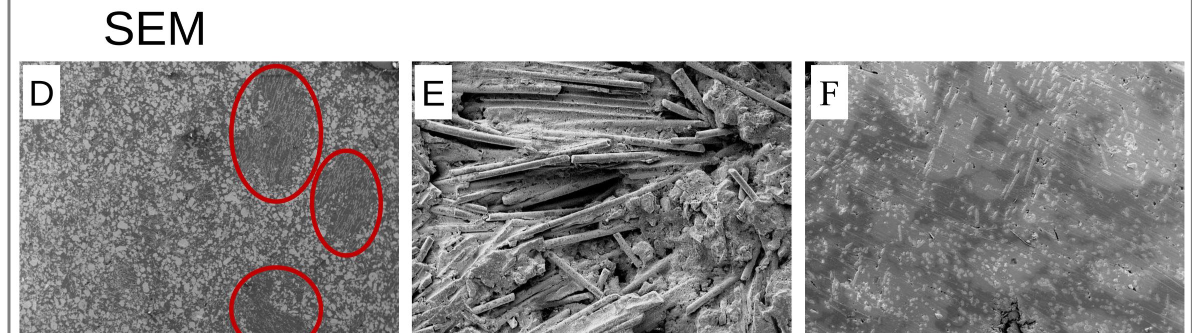
Optical



(A) PLA to copper ratio of 1:1 (B) PLA to copper ratio of 1:1.5 (C) PLA to copper ratio of 1:2

Microstructure analysis of various compositions shows heterogeneous mixture of PLA and copper. Increasing amount of copper in the mixture yielded better distributions and in turn better thermal properties.

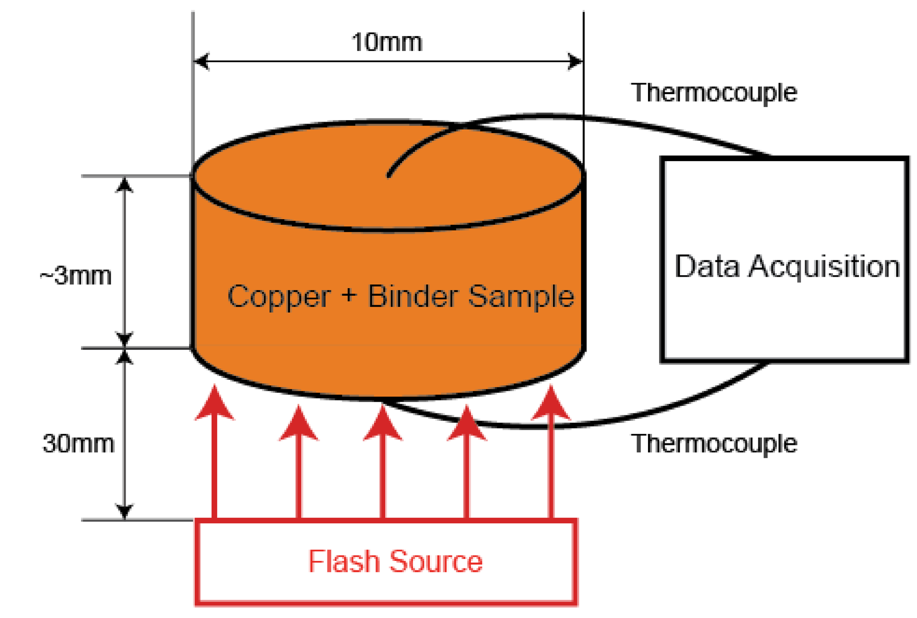
SEM



(D) Circled areas show glass fiber aggregations (E) Close up of glass fiber region (F) Pure PLA sample indicating even glass fiber distribution

Investigations into distribution of glass fibers (E) indicated they aggregated (D) in the composite while being evenly distributed in pure PLA (F). Glass fibers add fracture toughness and thermal conductivity to PLA, so a more even distribution is desired.

Flash Heating Diagram



Business

MSE Ballistics seeks to offer a safer alternative to conventional ammunition, at a competitive price. Explosive mechanisms for self-destruction are currently employed in several ammunition designs. There are several non-lethal weapon systems like Tasers or rubber bullets, but nothing that allows for a lethal to non-lethal transition. Additionally, frangible bullets require an impact for destruction. The MSE solution is unique in its simplicity, requiring no explosives or hazardous materials in the projectile and can transition to non-lethal in flight.

Bullet Type	Cost per Round (.45 Caliber)	Easily Produced	Lethal Within Effective Range	Safe Beyond Effective Range
MSE Ballistics	$1.80	✓	✓	✓
Standard	$0.25~$3.00	✓	✓	✗
Safety (Frangible)	$0.50~$3.25	✓/✗	✓	✗
Rubber/ Plastic	~$0.40	✓	✗	✓

Conclusion

The MSE Ballistics senior design team designed, fabricated, and tested a Cu-PLA composite material for ballistics application. Cu was chosen as the metal phase and PLA as the binder phase based on their mechanical properties, low cost, and thermal conductivities. A stainless steel die with interchangeable parts was used as a mold. Thermal conductivity dramatically increases as more copper is introduced. When the ratio of copper to PLA was too high, there was insufficient binding causing the samples to remain as loose powder. Optical microscopy and SEM indicate a non-homogeneous mixture of copper, PLA, and randomly oriented aggregates of aligned glass rod fibers. The best composition for making the bullets is a PLA to copper ratio of at least 1:2.

Future Work

The ratio of metal/binder material needs to be further investigated to optimize the timing of the materials transformation resulting in the bullet disintegration. Experiments need to be conducted that simulate the heat and timing generated during the bullet firing and ignition of the internal heat source to verify the rapid disintegration of the projectile. Validation of materials optimization, heat transfer and projectile disintegration to be verified and further optimized in actual live firing tests.