A composite penetrator or projectile is formed of a core of uniaxial tungsten wires embedded in a matrix material. The core may be overwrapped to improve hoop or radial strength. The core is mounted in a sabot for use as an ordnance projectile. The penetrator is frangible and can include a detonable energetic resin to provide a self-destruct capability. A pultrusion process is provided to manufacture the penetrator.
PULTRUDED COMPOSITE FRANGIBLE PROJECrILE OR PENETRATOR

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 60/962,037, filed Jul. 26, 2007, the disclosure of which is incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] N/A

BACKGROUND OF THE INVENTION

[0003] Penetrating weapons effectively use projectiles or penetrators formed of monolithic metal, such as depleted uranium or tungsten. Depleted uranium (DU) performs well as a penetrator due to its very high density, relatively low modulus-to-density ratio, and a shear failure characteristic that tends to cause penetrators fabricated from DU to be "self-sharpening." The use of DU can, however, present an environmental hazard. Monolithic tungsten alloy penetrators are slightly less dense than DU penetrators, with approximately twice the elastic modulus and four times the compressive strength. Monolithic tungsten penetrators perform well, although not as well as DU penetrators.

[0004] Rapid fire gun systems have been designed as point defense weapons, for example, to protect Navy ships against high speed anti-ship missiles, by destroying incoming rounds prior to impact. These systems rely on very high rates of fire combined with automatic adjustment of the aim point based on projectile trajectory tracking to maximize the probability that at least one projectile will hit an incoming missile. Such projectiles rely on kinetic energy to target destruction, so extremely dense monolithic penetrator materials such as depleted uranium or tungsten are used to maximize lethality.

[0005] Because this strategy relies on a high rate of fire, a significant number of projectiles miss the target. This creates a potential for collateral damage and casualties from the projectiles that miss the target when used, for example, in urban or heavily populated areas. One approach for reducing collateral damage is to use projectiles with integral self-destruct mechanisms. This approach currently precludes the use of kinetic energy penetrators, however, because the monolithic metal penetrator remains lethal for personnel throughout the projectile flight path. Another alternative is to use a much less lethal high explosive round with a self-destruct mechanism. However, the effectiveness of an incoming missile is lowered. Also, composite or axially reinforced penetrators have not generally been found to be effective at surviving centrifugal forces generated in rifled gun systems.

SUMMARY OF THE INVENTION

[0006] A composite projectile or penetrator is provided that is formed of unidirectional tungsten or other wires embedded in a matrix material. Tungsten wires are readily available and commoditized. The matrix material constituents can be epoxy or other polymer resins or low melting point eutectic alloys. Unidirectional composite penetrators can be over-wrapped with graphite or other fibers to provide improved hoop-radial strength, which improves the penetrator's capability in rifled gun systems.

[0007] In one aspect, a composite projectile is provided that includes a self-destruct mechanism that reduces or eliminates the potential for collateral damage while retaining the ability to successfully destroy targets. The self-destruct mechanism breaks the penetrator into small, non-lethal elements with a lower kinetic energy that minimizes the potential for collateral damage or injury.

[0008] A cost-effective automated pultrusion manufacturing process in combination with commodity components provides a simpler, lower cost production process than current monolithic metal processing.

DESCRIPTION OF THE DRAWINGS

[0009] The invention will be more fully understood by reference to the following detailed description of the invention in conjunction with the drawings, of which:

[0010] FIG. 1 illustrates an embodiment of a composite material penetrator according to the present invention;

[0011] FIG. 2 illustrates the penetrator of FIG. 1 mounted in a sabot;

[0012] FIG. 3A is an isometric view of a frangible self-destruct penetrator according to the present invention;

[0013] FIG. 3B is a cross-sectional view of the penetrator of FIG. 3A;

[0014] FIG. 3C is an exploded view of the penetrator of FIG. 3A;

[0015] FIG. 4A is an embodiment of a wire bundle layout for a self-destruct penetrator of the present invention;

[0016] FIG. 4B is a further embodiment of a wire bundle layout for a self-destruct penetrator of the present invention;

[0017] FIG. 5 is a schematic illustration of a pultrusion process for the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The disclosure of U.S. Provisional Application No. 60/962,037 is incorporated by reference herein.

[0019] A composite material penetrator 10 or projectile 12 are illustrated in FIGS. 1 and 2. The composite penetrator is formed of multiple unidirectional strands of wire 14, preferably tungsten, embedded in a matrix material 16 that bonds the wires together. An overwrapping 18 is preferably provided around the wire-matrix composite. The composite penetrator forms a core which can be held within a sabot 22 of any desired design, as known in the art. See FIG. 2. Any suitable projectile configuration may be employed.

[0020] The unidirectional wires are preferably tungsten or substantially tungsten, as tungsten is generally effective in ordnance projectiles, and tungsten wire is a commodity readily available for light bulbs. Boron, graphite, or other fibers or wires can be added in both the longitudinal direction and the hoop-bias direction (as the overwrapping) to improve weight-specific bending strength and rigidity of the penetrator.

[0021] The matrix material may be an epoxy resin or other polymer or a metal. In one embodiment, the matrix material is an energetic polymer resin, as would be known in the art, to provide a self-destruct mechanism, discussed further below. Suitable energetic resins are known in the art. Strength characteristics are best provided by a plastic matrix material having a large strain to failure ratio and good adhesion to the
tungsten or other wires. The class of soft metals known as Cerro alloys or Woods metals possesses these attributes as well as superior density and modulus compared with polymer matrix materials. Other suitable matrix materials may include low temperature melting eutectic alloys, such as lead-tin-bismuth or tin-bismuth alloys. These alloys have melting temperatures in a range (approximately 200–400° F.) similar to the curve temperatures for epoxy and other polymers, so they are suitable for low temperature processing. If necessary, the surface of the tungsten wires can be suitably prepared to improve the wetting of the metal matrix material and bonding to the wires, to minimize wire pullout.

[0022] The radial/hoop strength is important for penetrators launched by rifled gun systems (e.g., spin-stabilized projectiles). Spin-stabilized projectiles are often launched at rotational speeds in excess of 100,000 rpm, leading to hoop and radial stresses often well in excess of 5000 psi. While the applied rotational stresses vary widely with the particular ordnance application, they can easily exceed the transverse strength capability of unidirectional composite materials having a resinous or low-melt eutectic alloy matrix. Thus, the resistance of spin stabilized projectiles to the centrifugal load-induced stresses is an important consideration for composite penetrators. In one embodiment, radial/hoop strength can be improved by an overwrapping of graphite, boron, or other fibers, discussed further below.

[0023] The particular size and configuration of the core of the composite penetrator is based on target effect, post self-destruct lethality (if present), and load requirements. Specific considerations include wire diameters; wire lay-up pattern; penetrator size; external elements including sabot, pusher plate and nose cap (described below); firing loads; target impact induced loads; and projectile dynamic stability during flight. The design must meet lethality requirements both before and after the self-destruct mechanism function as well as all aerodynamic and dynamic flight stability requirements.

[0024] Other considerations relevant to penetrator design include selection of materials and configuration so that the penetrator exhibits sufficiently high hardness and compressive strength and high density. Additionally, a reasonably large value of transverse strain to failure is desirable to ensure a stable penetration. Sleeving or otherwise improving penetrator bending rigidity and strength is also desirable, especially on a weight-specific basis. The use of boron fiber in addition to the tungsten wires can be helpful in this regard, as it provides a higher modulus (58 Msi) and lower density (2.2 g/cc) compared to tungsten (59 Msi and 19.65 g/cc).

[0025] In one embodiment, a composite kinetic energy penetrator includes multiple unidirectional strands of tungsten wire embedded in an energetic polymeric resin to provide the self-destruct mechanism that breaks the penetrator into small individual wire elements that fall to the ground with significantly lower potential for damage or injury than a more conventional monolithic penetrator. These segments rapidly bleed off energy as they become unstable and tumble. The inclusion of a sufficient amount of energetic resin to support self-destruction introduces a trade-off between optimum wire packing for self-destruction versus maximum weight and density of the penetrator.

[0026] FIGS. 3A-3C illustrate an embodiment of a frangible self-destruct projectile 26 in which a core bundle 32 of pultruded wires embedded in a matrix material is shown with a pusher plate 34 and a central rod 36 supporting an energetic material insert 38 inside a light-weight nose fairing or cap 42. The pusher plate assists in maintaining penetrator integrity during firing, and the nose cap is provided for both penetrator integrity and ballistic performance. After a pre-determined, chemically triggered time, the energetic material detonates, in any suitable manner, as would be known in the art. Detonation splits the nose fairing and drives the rod backwards to split the wires apart, while also splitting the pusher plate. During a target impact, the energetic material is designed to resist detonation until the penetrator has almost or fully penetrated the target. This results in another mechanism (beside the impact impulse) to destroy the target safely above the ground. After self-destruction, the individual pieces have a lesser kinetic energy (KE), so that they do not cause inappropriate damage upon impact with the ground.

[0027] An embodiment of a layout of a composite wire bundle 52 is illustrated in FIG. 4A, in which an energetic resin 54 binds the wires 56 together. This embodiment imposes a minimum gap size between wires to allow sufficient resin for effective self-destruct functioning, which may limit the overall density.

[0028] A further embodiment of a layout of a composite wire bundle 62 is illustrated in FIG. 4B. In this embodiment, the energetic material is concentrated by utilizing a pultrusion process (discussed below) to leave out individual wires to create a larger space between the wires 66. The penetrator is pultruded with a placeholder material in place of selected wires. The placeholder is then removed, for example, by heating or chemical action, leaving passage(s) for the self-destruct pyrotechnic material 64 to be placed.

[0029] A composite penetrator can be built up from tungsten or other wires, and possibly other structural fiber such as carbon or glass, in a pultrusion process, which is well suited to low cost, high volume production. An automated low temperature process such as pultrusion coupled with low cost, commodity components such as tungsten wire suitable for light bulbs provides a simpler production process that makes tungsten projectiles much more cost effectively than current technology for making large diameter monolithic tungsten rods.

[0030] Pultrusion processing is capable of automating the manufacture of cost-effective constant cross section parts with little labor cost. A composite design, optimized for pultrusion production, can reduce the cost of the system components to a minimum, approaching raw material cost, for sufficiently large production runs. The process is illustrated schematically in FIG. 5, in this case using an injection system to impregnate a fiber preform with resin. In the pultrusion process, reinforcing materials in the form of dry unidirectional fibers, cloth, multi-axial stitch bonded materials, braided pre-forms and specially-produced 2-D and 3-D reinforced materials are continuously pulled from spools or woven using in-line winders and braiders prior to being passed through an optional preheating furnace.

[0031] Preheating serves to dry the materials and improves resin wet-out. The collation of dry reinforcing material then passes through forming cards before entering a heated steel die. Tungsten wires or rods should be properly collimated before entering the die, as they are not sufficiently flexible to redistribute themselves once in the die or upstream guides. Similarly, the wires should be packed as tightly as possible with no or little free space to prevent shifting and crossover of wires in the die. One or more forming cards or guide plates include holes drilled for each individual wire in the appropriate wire pattern to collimate the wires. The die compresses the
material into the final geometry. Resin is applied to the pre-
form, either by pulling it through a bath or by directly
injecting liquid matrix into the die. The wet fiber/resin as-
sembly is then cured as it moves through the heated portion of
the die. The resin inside the die is exposed to the appropri-
tate temperature and pressure conditions required to achieve
a nearly complete cure before the material exits the down-
stream end of the tool.

[0032] The epoxy resin can be filled with a fine kaolin clay
to raise the viscosity to a paste-like or near paste-like consis-
tency. The increased viscosity helps to prevent loss of resin
from between the wires, maintain a resin film between wire
contact points, and minimize shrinkage and microcracking. A
mold release agent can be used when the resin contacts the die
surface, such as on outer carbon fibers.

[0033] Line speed and temperature can be regulated to
obtain the desired cure properties and overall composite prop-
erties. A set of hydraulic gripping plates alternately grab
and pull the material through the system at a constant speed.
Tractor-puller systems are also used for simpler part geomet-
ries.

[0034] The composite core can be overwrapped, for
example, with graphite or other fibers, for greater transverse
strength and to provide a desired outer diameter, either before
or after passage through the pulltunnel die. For example, a
pultruded length of core can be wet filament wound with a
yarn of carbon fiber at a suitable wind angle, preferably as
close to 90° (hoop direction) as practical. The same resin used
for pulltunnel of the core can be used for the filament winding.
The pultruded core surface can be lightly sanded and solvent
wiped prior to winding. Any suitable number of layers of the
overwrapping fiber can be wound. The part is then wrapped
with shrink film and cured at a suitable temperature. After
removal of the shrink wrap, the part can be lightly sanded to
removed ridges left by the shrink film and to bring the diam-
eter down to the correct size to fit the sabot. The resulting
overwrapped composite wire bundle is cut into pieces of the
desired length. The wire bundle segments are mounted in
sabots of the desired caliber. If the segments are intended for
self-destruct projectiles, the other components for the self-
destruction mechanism (as discussed above) are assembled
with the segments. A more aerodynamic shape and better
stability of the projectile can be provided using suitable com-
ponents, for more effective penetration into the various mis-
ile threats if desired.

[0035] The composite tungsten wire penetrator can also
be made by batch processes, such as pressure casting.

[0036] Hybrid penetrators can also be provided that com-
bine composite materials with metal, such as steel. For
example, the penetrator can be longitudinally segmented such
that some portion of the wall thickness of a metal penetrator
is replaced with a composite material to improve compression
strength and modulus.

[0037] The present frangible projectile is advantageous for
several reasons. Its use reduces the likelihood that expended
projectiles fall to earth and injure unintended victims or dam-
age building and equipment that were not specifically tar-
geted. Also, the composite projectile eliminates or reduces
difficult and expensive processing required to manufacture a
monolithic tungsten penetrator, replacing it with a readily
available, low cost material that retains the ability to penetrate
armored targets.

[0038] The design of the penetrator allows for a weight of
55-75% of that of a monolithic penetrator, depending on wire
size and materials used, while providing a simple means for
breaking the penetrator into fragments that are significantly
less lethal.

[0039] The projectile is useful for military application,
civilian law enforcement agencies, and hunters who use high
power rifles.

[0040] The invention is not to be limited by what has been
particularly shown and described, except as indicated by the
appended claims.

1. A composite penetrator comprising:
a core comprising tungsten wires disposed uniaxially, the
tungsten wires embedded in a matrix material, the
uniaxial tungsten wires defining a longitudinal direction
of the core;
an overwrapping over the core, the overwrapping compris-
ing a filament winding wound in a hoop direction around
the core at a wind angle of 90° or close to 90° to the
longitudinal direction of the core to increase the trans-
verse strength of the core; and
a sabot containing the core and the overwrapping.

2. The penetrator of claim 1, wherein the matrix material
comprises a detonatable energetic resin.

3. The penetrator of claim 1, further comprising a pusher
plate and a nose cap maintaining the core, a rod disposed
through the core, and a detonatable energetic resin.

4. The penetrator of claim 1, wherein the matrix material
comprises a eutectic alloy.

5. The penetrator of claim 1, wherein the matrix material
comprises a Cerro alloy.

6. The penetrator of claim 1, wherein the matrix material
comprises a Woods metal.

7. The penetrator of claim 1, wherein the matrix material
comprises a lead-tin-bismuth alloy or a tin-bismuth alloy.

8. The penetrator of claim 1, wherein the overwrapping is
comprised of boron fibers.

9. The penetrator of claim 1, wherein the overwrapping is
comprised of graphite fibers.

10. The penetrator of claim 1, further comprising boron
fibers disposed uniaxially with the tungsten wires in the core.

11. The penetrator of claim 1, further comprising graphite
fibers disposed uniaxially with the tungsten wires in the core.

12. A method of manufacturing the composite penetrator
of claim 1, comprising:
collimating a plurality of tungsten wires through a forming
card in a desired layout;
wetting out the collimated tungsten wires with a matrix
material;
pulling the tungsten wires through a pulltunnel die for a
selected time and at a selected temperature to form a
pultruded length of composite material;
cutting the composite material into segments; and
mounting the segments into sabots.

13. The method of claim 12, further comprising wetting out
the collimated tungsten wires in a bath of resin.

14. The method of claim 13, wherein the resin comprises a
detonatable energetic resin.

15. The method of claim 12, further comprising wetting out
the collimated tungsten wires in a bath of a eutectic alloy.

16. The method of claim 12, further comprising providing an
overwrapping over the tungsten wires.
17. The method of claim 16, wherein the overwrapping is wound over the pultruded length after exiting the pultrusion die.

18. The method of claim 16, wherein the overwrapping is wound over the tungsten wires prior to entering the pultrusion die.

19. The penetrator of claim 1, wherein the matrix material comprises a resinous material.

20. The penetrator of claim 1, wherein the matrix material comprises a resinous material or a low-melt eutectic alloy.