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Inventor(s)	Austin, II; David et al.

MULTI-PART SHAPED CHARGE LINER

Abstract

The present disclosure relates to a shaped charge liner. The shaped charge liner includes a first liner portion formed a first material. The first liner portion has an apex and a skirt section that define an interior volume of the first liner portion. The shaped charge liner also includes a second liner portion formed of a second material. The second liner portion is coupled to the first liner portion such that the second liner portion is an edge of the interior volume.

Inventors: **Austin, II; David (Rosharon, TX), Fuller; John (Rosharon, TX)**

Applicant: **Schlumberger Technology Corporation** (Sugar Land, TX)

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Background/Summary

BACKGROUND

[0001] The present disclosure generally relates to systems and methods for shaped charge liners having multiple parts.

[0002] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admission of prior art.

[0003] Exploring, drilling, and completing hydrocarbon and other wells are generally complicated, time consuming and ultimately very expensive endeavors. As a result, over the years, well architecture has become more sophisticated where appropriate in order to help enhance access to underground hydrocarbon reserves. For example, as opposed to wells of limited depth, it is not uncommon to find hydrocarbon wells exceeding 30,000 feet in depth. Furthermore, as opposed to remaining entirely vertical, today's hydrocarbon wells often include deviated or horizontal sections aimed at targeting particular underground reserves.

[0004] While such well depths and architecture may increase the likelihood of accessing underground hydrocarbon reservoirs, other challenges are presented in terms of well management and the maximization of hydrocarbon recovery from such wells. For example, during the life of a well, a variety of well access applications may be performed within the well with a host of different tools or measurement devices. However, providing downhole access to wells of such challenging architecture may require more than simply dropping a wireline into the well with the applicable tool located at the end thereof. Indeed, a variety of isolating, perforating, and stimulating applications may be employed in conjunction with completions operations.

[0005] In the case of perforating, different zones of the well may be outfitted with packers and other hardware, in part for sake of zonal isolation. Thus, wireline or other conveyance may be directed to a given zone and a perforating gun employed to create perforation tunnels through the well casing. Specifically, shaped charges housed within a steel gun may be detonated to form perforations or tunnels into the surrounding formation, ultimately enhancing recovery therefrom.

[0006] The profile, depth, and other characteristics of the perforations are dependent upon a variety of factors in addition to the material structure through which each perforation penetrates. That is, the jet formed by the detonation of a given shaped charge may pierce a steel casing, cement, and a variety of different types of rock that make up the surrounding formation. However, characteristics of different components of the shaped charge itself may determine the characteristics of the jet, and ultimately the depth, profile, and overall effectiveness of each given perforation as described herein.

[0007] Among other components, a shaped charge generally includes a case, explosive pellet material, and a liner member. Thus, detonation of the explosive within the case may be utilized to direct the liner away from the gun and toward the well wall as a means by which to form the noted jet. Therefore, the characteristics of the jet are largely dependent upon the behavior of the liner and other shaped charge components upon detonation. For example, a solid copper or zinc liner may be utilized to generate a jet of considerable stretch with a head or tip that travels at 5-10 times the rate of speed as compared to the speed at the tail. Depending on the casing thickness, formation type, and other such well-dependent characteristics, this type of liner is generally of notable effectiveness in terms of achieving substantial depth of penetration.

BRIEF DESCRIPTION

[0008] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0009] In one embodiment, the present disclosure is directed to a shaped charge liner. The shaped charge liner includes a first liner portion formed of a first material. The first liner portion has an apex and a skirt section that define an interior volume of the first liner portion. The shaped charge

liner also includes a second liner portion formed of a second material. The second liner portion is coupled to the first liner portion such that the second liner portion is an edge of the interior volume.
[0010] In one embodiment, the present disclosure is directed to a shaped charge. The shaped charge includes a casing member and an explosive component positioned within an interior volume of the casing. The shaped charge also includes a multi-material liner coupled to the explosive component. The multi-material liner includes a first liner portion and a second liner portion. The first liner portion is disposed between the explosive component and the second liner portion. The second liner portion is in contact with a surface of the first liner portion along an apex of the first liner portion.
[0011] In one embodiment, the present disclosure is directed to a method. The method includes forming a first shaped charge liner portion using a first material. The method also includes forming a second shaped charge liner portion using a second material. Further, the method includes coupling the second shaped charge liner portion to a surface of the first shaped charge liner portion.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0012] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:
[0013] FIG. **1** shows a perforation operation, in accordance with aspects of the present disclosure;
[0014] FIG. **2** shows a diagram illustrating a perforation being made with a perforation gun, in accordance with aspects of the present disclosure;
[0015] FIG. **3** shows a diagram illustrating a perforation and a tunnel made with a shaped charge, in accordance with aspects of the present disclosure;
[0016] FIG. **4** shows a cross-sectional view of an embodiment of a shaped charge, in accordance with aspects of the present disclosure;
[0017] FIG. **5**A shows a diagram of the shaped charge of FIG. **4** forming a first type of jet, in accordance with aspects of the present disclosure;
[0018] FIG. **5**B shows a diagram of the shaped charge of FIG. **4** forming a second type of jet, in accordance with aspects of the present disclosure;
[0019] FIG. **5**C shows a diagram of the shaped charge of FIG. **4** forming a third type of jet, in accordance with aspects of the present disclosure;
[0020] FIG. **6** shows a cross-sectional view of an embodiment of a shaped charge that includes a first example of a multi-part shaped charge liner, in accordance with aspects of the present disclosure;
[0021] FIG. **7** shows a cross-sectional view of an embodiment of a shaped charge that includes a second example of a multi-part shaped charge liner, in accordance with aspects of the present disclosure;
[0022] FIG. **8** shows a cross-sectional view of an embodiment of a shaped charge that includes a third example of a multi-part shaped charge liner, in accordance with aspects of the present disclosure; and
[0023] FIG. **9** shows a flow diagram of a method for assembling a multi-part shaped charge liner, in accordance with aspects of the present disclosure.
DETAILED DESCRIPTION
[0024] One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation,

as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0025] When introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “one embodiment” or “an embodiment” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0026] As discussed above, shaped charges are used for a variety of oil and gas applications. In particular, the jet formed by the detonation of a given shaped charge may pierce a steel casing, cement, and a variety of different types of rock that make up the surrounding formation. The characteristics of the jet produced by a shaped charge are largely dependent upon the behavior of the liner and other shaped charge components upon detonation. At least in some instances, it may be advantageous to produce a jet from a material of a collapsing liner to puncture or sever certain areas in a wellbore, while not severing others. For example, it may be advantageous to sever a control line behind a completion prior to cementing as part of a plug and abandonment operation. To create such a jet, it may be advantageous to use relatively high density materials (e.g., metals) to form the liner in the shaped charge. However, there may be certain limitations in pressed liners or green compacts (e.g., pressed components) for shaped charges. As referred to herein, a “green compact” is a compact formed by pressurizing and cooling a powder to form a dense, solid mass, where the powders are held together by friction between the particles, as opposed to sintering the metal powders. As referred to herein, a “green density” refers to the density of a pressed compact. To improve techniques for green compact liners, it is advantageous to develop techniques to provide more density within the shaped charge.

[0027] Accordingly, the present disclosure relates to a multi-part shaped charge liner (e.g., multi-material shaped charge liner). In general, the multi-part shaped charge liner includes multiple liner parts or portions (e.g., a first liner portion and a second liner portion). In certain embodiments, the first liner portion may encapsulate the second liner portion. For example, the first liner portion may include an apex and a skirt section that define an interior volume of the first liner portion. In such an embodiment, the second liner portion is disposed within the first linear portion such that the second liner portion at least partially surrounds the interior volume. For example, the second liner portion may be in contact with an outer surface of the apex, an outer surface of the skirt section, or both. However, in certain embodiments, the second liner portion may be disposed on an exterior of the first liner portion and, thus, be coupled to the apex of the first liner portion. In some instances, the second liner portion may be formed of a denser material. In any case, upon detonation of the explosive component, the first liner portion and the second liner portion collapse to form a denser material that provides more momentum to the resulting jet as compared to green, pressed liners formed from conventional techniques.

[0028] With reference to FIG. **1**, after a well **10** is drilled, a casing **12** is typically run in the well **10** and cemented to the well **10** in order to maintain well integrity. After the casing **12** has been cemented in the well **10**, one or more sections of the casing **12** that are adjacent to the formation zones of interest (e.g., target well zone **13**) may be perforated to allow fluid from the formation zones to flow into the well for production to the surface or to allow injection fluids to be applied into the formation zones. To perforate a casing section, a perforating gun string may be lowered into the well **10** to a desired depth (e.g., at target zone **13**), and one or more perforation guns **15** may be fired to create openings in the casing **12** and to extend perforations into the surrounding formation **16**. Production fluids in the perforated formation **16** can then flow through the perforations and the casing openings into the wellbore **11**.

[0029] Typically, perforating guns **15** (which include gun carriers and shaped charges mounted on or in the gun carriers or, alternatively, include sealed capsule charges) are lowered through tubing or other pipes to the desired formation interval on a line **17** (e.g., wireline, e-line, slickline, coiled tubing, and so forth). The charges carried in a perforating gun **15** may be phased to fire in multiple directions around the circumference of the wellbore **11**. Alternatively, the charges may be aligned in a straight line. When fired, the charges create perforating jets that form holes in the surrounding casing **12** as well as extend perforation tunnels into the surrounding formation **16**.

[0030] With reference to FIG. **1**, certain embodiments of the present disclosure include a perforation system comprising: (1) a perforating gun **15** (or gun string), wherein each gun may be a carrier gun (as shown) or a capsule gun (not shown); and (2) one or more improved shaped charges **20** loaded into the perforating gun **15** (or into each gun of the gun string), each charge having a liner member, as described herein; and (3) a conveyance mechanism **17** for deploying the perforating gun **15** (or gun string) into a wellbore **11** to align at least one of said shaped charges **20** within a target formation interval **13**, wherein the conveyance mechanism may be a wireline, tubing, or other conventional perforating deployment structure; among other components.

[0031] Examples of explosives (e.g., explosive component as described in FIG. **4**) that may be used in the various explosive components (e.g., charges, detonating cord, and boosters) include RDX (cyclotrimethylenetrinitramine or hexahydro-1,3,5-trinitro-1,3,5-triazine), HMX (cyclotetramethylenetetranitramine or 1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane), TATB (triaminotrinitrobenzene), HNS (hexanitrostilbene), and others.

[0032] Referring to FIGS. **2** and **3**, the material from a collapsed liner of the shaped charge **20** (e.g., as described in more detail in FIG. **4**) forms a perforating jet **28** that shoots through the front of the shaped charge and penetrates the casing **12** and underlying formation **16** to form a perforated tunnel (or perforation tunnel) **40**. Around the surface region adjacent to the perforated tunnel **40**, a layer of residue **30** from the charge liner is deposited. The charge liner residue **30** includes “wall” residue **30**A deposited on the wall of the perforating tunnel **40** and “tip” residue **30**B deposited at the tip of the perforating tunnel **40**. As described in more detail with respect to FIG. **5**, adjusting properties of the shaped charge **20** (e.g., the geometry of the liner, the density of the liner, the mechanical strength of the liner, and so on) may adjust jet properties (e.g., jet velocity and/or jet shape) of the perforating jet **28**.

[0033] Referring now to FIG. **4**, a cross sectional view of an embodiment of a shaped charge **20** is shown. The shaped charge **20** includes a casing member **42** and an interior volume **44** that is defined by an explosive component **46** and a liner member **48**. The explosive component **46** is disposed between the casing member **42** and the liner member **48** such that the liner member **48** surrounds the interior volume **44**.

[0034] The liner member **48** may be formed of packed, powered metals and, in at least in some instances, non-metallic materials. The metals of the liner member **48** may include metals having a density of approximately 6 or greater grams per cubic centimeter (g/cc), 7 or greater g/cc, 8 or greater g/cc, 9 or greater g/cc, 10 or greater g/cc, 11 or greater g/cc, 12 or greater g/cc, or 13 or greater g/cc, and so on. In some embodiments, the metals of the liner member **48** may include metals having a density less than approximately 6 g/cc (e.g., aluminum, beryllium, titanium, and so on). For example, the liner member **48** may include copper (e.g., having a density of approximately 8.9 g/cc) and/or lead (e.g., having a density of approximately 11.3 g/cc). In some embodiments, the liner member **48** may include tungsten (e.g., having a density of approximately 19.3 g/cc). In some embodiments, the liner member **48** may include a mixture of metals, which may provide a desired density. For example, the liner member **48** may include approximately 50 weight percent (wt %) or greater, approximately 60 wt % or greater, approximately 70 wt % or greater, approximately 80 wt

% or greater, or approximately 90 wt % or greater of a first metal (e.g., tungsten). Further, the liner member **48** may include a remaining wt % of a second metal (e.g., copper or lead), such as approximately 10 wt % or less, 20 wt % or less, 30 wt % or less, and so on.

[0035] As mentioned above, the liner member **48** may also include non-metallic materials, such as nitrides, carbides, oxides, diamond, ceramic materials, or a combination thereof. For example, the liner member **48** may include relatively low density materials (e.g., as compared to the metals), such as SiC, Si.sub.3N.sub.4, SiO.sub.2, B.sub.4C, B.sub.4N, ZnO, TiC, Li.sub.3N, TiO.sub.2, Mg.sub.3N.sub.2, and other relatively low density non-metallic materials. In some embodiments, the liner member **48** may include a polymer material, such as fluorinated polymers (e.g., polytetraflouroethylene). In some embodiments, the liner member **48** may include metal-polymer composite mixtures. In such embodiments, the liner member **48** may include a first weight percent (wt %) (e.g., first amount) of one or more metals and a second wt % of one or more non-metallic materials. For example, the liner member **48** may include approximately 50 wt % or greater, 60 wt % or greater, 70 wt % or greater, 80 wt % or greater, 90 wt % or greater of one or more metals. As such, the liner member 48 may include approximately 50 wt % or less, 40 wt % or less, 30 wt % or less, 20 wt % or less, or 10 wt % or less of one or more non-metallic materials.

[0036] Referring specifically now to FIGS. **5**A, **5**B, and **5**C (e.g., collectively FIGS. **5**A-**5**C), side cross-sectional views of a different types of shaped charges **20***a*, **20***b*, and **20***c* in use during perforating applications are shown. That is, in each case, a charge **20***a*, **20***b*, and **20***c* has been loaded into a perforating gun (not shown), and utilized in a perforating application in a well **10**. The charges **20***a*, **20***b*, and **20***c* may be made up of generally the same features described with respect to FIG. **1**. For example, the charges **20***a*, **20***b*, and **20***c* may include the same type of casing **12** and explosive component **46**. However, in each case, a different type of liner member **48***a*, **48***b*, and **48***c* may be used to provide a different type of charge **20***a*, **20***b*, and **20***c* for a different type of perforating application.

[0037] With reference to FIG. **5**A in particular, a deep penetrating jet shaped charge **20***a* is shown. Upon detonation, a deep penetrating jet **28***a* is formed and directed at the casing **12** that defines the well **10**. Ultimately, this forms a perforation tunnel **40***a* that penetrates through the casing member **42**, cement **49**, and into the adjacent formation **16** so as to aid in hydrocarbon recovery therefrom. In the embodiment shown, the liner **48***a* that is used to form the jet **28***a* and achieve such penetration may be a comparatively thin but high-density tungsten-based liner member **48***a* so as to form a thinner and longer jet **28***a*. The end result, depending largely on the particular characteristics of the casing **12**, may be a perforation tunnel **40***a* of between approximately **30** and approximately **40** inches deep with a diameter of between approximately 0.3 inches and approximately 0.4 inches.

[0038] Of course, as depicted in the embodiment of FIG. **5**B, a different type of liner **48***b* may be utilized to obtain a different type of charge **20***b* and performance during perforation. More specifically, in the embodiment of FIG. **5**B, a side cross-sectional view of wide jet shaped charge **20***b* is shown. In this case, the liner member **48***b* is of a comparatively thicker dimensions and lower density, perhaps with a lower percentage of tungsten. Thus, a comparatively thicker or wider jet **28***b* may be formed. The end result, again depending on characteristics of the casing **12** and other physical factors, may be a shorter perforation tunnel **40***b* that is closer to a threshold distance (e.g., 60-90 cm deep but with a wider diameter (e.g. between about 1 cm and about 1.3 cm).

[0039] Referring now to FIG. **5**C, a side cross-sectional view of a combination jet shaped charge **20***c* is shown. In this case, the liner member **48***c* may be of a thickness, density, materials and other characteristics similar to either of the deep penetrating **48***a* or wide **48***b* liner member types described above. However, the combination liner member **48***c* of FIG. **5**C is of a uniquely tailored non-uniform morphology. Thus, a combination jet **28***c* may ultimately be formed such that the perforation tunnel **40***c* which is formed is also of a uniquely tailored morphology.

[0040] Accordingly, FIGS. **5**A-**5**C show that altering physical properties (e.g., density) of the liner member **48** adjusts the shape of the resulting jet **28**. That is, by altering the explosive component

46, the liner **48**, and/or mass distributions of an axisymmetric shaped charged design, the charge may be converted to an alternate symmetry. It is presently recognized that for cutting control lines, it may be advantageous to use a shaped charge having a planar symmetry, whereby mass is added or removed at pole 180 degrees apart. As a result, during jet collapse, the normally axially uniform fast-moving jet is converted to a slower fan-like geometry that cuts the line spanning multiple degrees from the axis of symmetry serves to provide increase coverage of the cutter while still achieving velocities and densities inside the cutting fan, which are comparable to linear slot cutters, but which can utilize existing hardware and manufacturing methods.

[0041] As described herein, it is presently recognized that it may be advantageous to form a liner member **48** that includes two or more metals (e.g., metal powders) or metal powder mixtures to provide a density in a location within the interior volume **44**, as discussed below, in an advantageous location to provide a desired geometry of the jet. In some embodiments, the liner **48** may have high average green density and low average density after pressing. FIG. **6** shows a cross-sectional view of a shaped charge **20** having a multi-part shaped charge liner **50** in accordance with the present disclosure. In general, the multi-part shaped charge liner **50** includes multiple layers, multiple parts, or multiple portions formed of different materials that are green compacts, which provide more green density to improve the momentum of the jet formed from detonation.

[0042] As shown in FIG. **6**, the multi-part shaped charge liner **50** includes a first liner portion **52** and a second liner portion **54**. As illustrated, the first liner portion **52** includes a generally conical shape having an apex **56** and a skirt section **58** (e.g., that gradually extends radially outward from the apex **56** to an axial end of the skirt section **58**, for example, relative to an axis **72**). The apex **56** and the skirt section **58** generally define the interior volume **44** (e.g., inner volume) of the multi-part shaped charge liner **50** as described herein. The first liner portion **52** contacts an inner surface (not shown) of the second liner portion **54**.

[0043] In some embodiments, the first liner portion **52** includes a mixture of metals and non-metallic materials. For example, the first liner portion **52** may be a green compact formed of a powder include one or more metals and one or more non-metallic materials. Additionally or alternatively, the second liner portion **54** may include a mixture of metals and non-metallic materials. In some embodiments, the first liner portion **52** may be formed of relatively denser materials than the second liner portion **54**. In some embodiments, the first liner portion **52** may be formed using machined metal parts, injected molded plastic parts, ceramic parts, metallic or non-metallic powders, or a combination thereof. However, in some embodiments, the first liner portion **52** and the second liner portion **54** may be formed of the same material.

[0044] As illustrated, the second liner portion **54** is in contact with the outer surface **60** (e.g., outer liner surface) (e.g., relative to the shaped charge **20**) of the first liner portion **52**. In particular, the second liner portion **54** contacts the outer surface **60** along the apex **56** of the first liner portion **52**. However, at least in some instances, the second liner portion **54** may contact the outer surface **60** that generally runs along the skirt section **58**, as described in more detail with respect to FIG. **7**. In any case, the first liner portion **52** is disposed between the second liner portion **54** and the explosive component **46** such that the second liner portion **54** contacts or is otherwise a surface that is along an edge of the interior volume **44** of the shaped charge **20**. As discussed above, upon detonation of the explosive component **46**, the second liner portion collapses inward to form a perforating jet **28**.

[0045] In the illustrated embodiment, the second liner portion **54** is disposed within, or otherwise contacts, the apex **56** of the first liner portion **52**. As such, the multi-part shaped charge liner **50** includes a relatively larger volume of material (e.g., metal powder and, in some instances, non-metallic material) at the apex **56** as compared to the skirt portion **58**. By providing the second liner portion **54** at the apex **56**, the multi-part shaped charge liner **50** may include different amounts of material at different portions of the multi-part shaped charge liner **50**. For example, the multi-part shaped charge liner **50** includes a first volume portion **62** that includes the first liner portion **52** and the second liner portion **54**. Further, the multi-part shaped charge liner **50** may include a second volume portion **64** that includes the first liner portion **52** and not the second liner portion **54**. Accordingly, the multi-part shaped charge liner **50** has a relatively higher density within the first volume portion **62** as compared to the second volume portion **64**. As discussed herein, it is presently recognized that increasing the density of certain portions of the multi-part shaped charge liner **50** may enable tuning of the shape of the resulting perforating jet **28**.

[0046] As another example, FIG. **7** shows a cross-sectional view of multi-part shaped charge liner **50**. In generally similar manner as described above with respect to FIG. **6**, the multi-part shaped charge liner **50** includes a first liner portion **52** having an apex **56** and a skirt section **58**. The apex **56** and the skirt section **58** generally define the interior volume **44** as described herein. Further, the multi-part shaped charge liner **50** includes a second liner portion **54**. The first liner portion **52** is disposed between the second liner portion **54** and the explosive component **46** such that the second liner portion **54** at least partially covers the outer surface **60** along the skirt section **58**.

[0047] In the illustrated embodiment, the second liner portion **54** is disposed within, or otherwise contacts, the apex **56** of the first liner portion **52**. Further, the second liner portion **54** at least partially extends along the skirt section **58** of the first liner portion **52**. As such, the multi-part shaped charge liner **50** includes a varying amount of material along the walls that define the interior volume **44**. For example, the multi-part shaped charge liner **50** may include a first volume of material (e.g., metal powder and, in some instances, non-metallic material) within at the apex **56**, a second volume of material at a first location along the skirt section **58**, and a third volume of material at a second location along the skirt section **58**.

[0048] As shown, the second liner portion **54** extends along a length portion **66** of the skirt section **58**. While the illustrated embodiment shows the second liner portion **54** extending along approximately half the skirt section **58**, it should be noted that the second liner portion may extend along any suitable portion of the skirt section **58**, such as 10% or less of the total length **68** of the skirt section **58**, 20% or less of the total length **68** of the skirt section **58**, 30% or less of the total length **68** of the skirt section 40% or less of the total length **68** of the skirt section **58**, 50% or less of the total length **68** of the skirt section **58**. In some embodiments, the second liner portion **54** may extend along a majority of the skirt section **58** (e.g., greater than 50% of the total length **68** of the skirt section **58**). For example, the second liner portion **54** may extend along 50% or greater of the total length **68** of the skirt section **58**, 60% or greater of the total length **68** of the skirt section **58**, 70% of greater of the total length **68** of the skirt section **58**, 80% or greater of the total length **68** of the skirt section **58**, 90% or greater of the total length **68** of the skirt section **58**.

[0049] Further, it should be understood that as FIG. **7** illustrates a cross-sectional view of the shaped charge **20**, the second liner portion **54** that extends along the length portion **66** of the skirt section **58** may be axially symmetric about the axis **72**. That is, the second liner portion **54** may be axially symmetric. However, in some embodiments, the second liner portion **54** and/or the first liner portion **52** may include regions that are planar symmetric, doubly planar symmetric, or other types of symmetries. It should be noted that tuning the symmetry of the multi-part shaped charge liner **50** may tune the shape and/or velocity of the resulting perforating jet **28**.

[0050] As noted above, the second liner portion **54** may be disposed on an exterior of the first liner portion **52** and, thus, be coupled to the apex of the first liner portion **52**. For example, the second liner portion **54** may be physically coupled to an outer first liner surface **60** of the first liner portion **52**. The outer first liner surface **60** generally includes or extends along the apex **56** as compared to the second liner portion partially surrounding the outer surface **60** as illustrated. In any case, the density within the volume of the charge **10** that includes the first volume portion that includes the first liner portion **52**. Further, the multi-part shaped charge liner **50** includes the second volume portion **64** that includes the first liner portion **52** and the second liner portion **54**, however, the second volume portion **64** includes relatively less of the second liner portion **54** than the first volume portion **62**. Accordingly, the multi-part shaped charge liner **50** has a relatively higher density within the first volume portion **62** as compared to the second volume portion **64**.

[0051] As shown, the thickness **70** of the second liner portion **54** along the length portion **66** is relatively even. However, in some embodiments, the thickness **70** of the second liner portion **54** along the length portion **66** and/or near the apex **56** may be variable. For example, the thickness **70** along the length portion **66** may vary in a periodic manner (e.g., increasing and decreasing), increase (e.g., linearly or exponentially), or decrease (e.g., linearly or exponentially), and so on. As another non-limiting example, the thickness **70** of the second liner portion **54** may be greater at the apex **56** while less thick along the skirt section **58**. Alternatively, the thickness **70** of the second liner portion **54** may be less at the apex **56** while thicker along the skirt section **58**. For example, the thickness **70** may vary at different axis positions along the axis **72**.

[0052] As shown, the thickness **70** of the second liner portion **54** is relatively constant. In some embodiments, the thickness **70** of the second liner portion **54** may decrease outwards towards the first liner portion **52** such that the second liner portion **54** may blend with the first liner portion **54**. In this way, the second liner portion **54** may terminate parallel to a plane that is normal to the direction of the jet (e.g., along axis **72**). For example, 15% or less, 10% or less, 5% or less, 4% or less, 3% or less, 2% or less, or 1% or less of the thickness **70** of the second liner portion **54** along the length **66** may decrease (e.g., linearly, or non-linearly) and, ultimately, terminate on a plane normal to the axis **72**.

[0053] In some embodiments, the first liner portion **52** and the second liner portion **54** of the multi-part shaped charge liner **50** may be formed along different axial positions about the axis **72**. To illustrate this, FIG. **8** illustrates a cross-sectional view of a third example of the multi-part shaped charge liner **50** in accordance with the present disclosure. In a generally similar manner as described with respect to FIGS. **6** and **7**, the multi-part shaped charge liner **50** includes the first liner portion **52** and the second liner portion **54**. As shown, the first liner portion **52** includes a generally conical shape having an apex **56** and a skirt section **58**. However, the first liner portion **52** may have any suitable shape or symmetry as described herein.

[0054] As shown in the illustrated embodiment, the first liner portion **52** is physically coupled to a first outer surface **67** of the explosive component **46**. Further, the second liner portion **54** is also physically coupled to a second outer surface **69** of the explosive component **46**. Accordingly, both the first liner portion **52** and the second liner portion **54** form the skirt section **58** of the multi-part shaped charge liner **50**. As shown, the first liner portion **52** extends along a first inner surface portion **74** of the total length **68** of the skirt section **58**. The second liner portion **54** extends along a second inner surface portion **76** of the total length **68** of the skirt section **58**. In such embodiments, the first liner portion **52** and the second liner portion **54** may not substantially overlap. Instead, the first liner portion **52** may abut the second liner portion **54**.

[0055] As described herein, the first liner portion **52** may be formed of a different material than the second liner portion **54**. Accordingly, in embodiments where the first liner portion **52** is formed of a denser material than the second liner portion **54**, the first volume portion **62** has a relatively higher density as compared to the second volume portion **64**.

[0056] In any case, as described herein, the disclosed techniques for forming the multi-part shaped charge liner **50** may provide a liner that forms a relatively denser green material and, thus, provide more momentum for the jet formed by detonation. FIG. **9** shows an example process **80** for forming the multi-part shaped charge liner **50** in accordance with the present disclosure. As shown, the process **80** includes, at block **82**, forming the first liner portion **52** using at least a first material. In general, the first liner portion **52** may be formed by press forming the material. At block **84**, the process **80** includes forming a second liner portion **54** using at least a second material. Then, at block **86**, the process **80** includes assembling the second liner portion **54** and the first liner portion **52**, thereby forming the multi-part shaped charge liner **50**.

[0057] In some embodiments, assembling the second liner portion **54** and the first liner portion **52** may include providing the second liner portion **54** onto the outer first liner surface **60** of the first liner portion **52**. For example, the second liner portion **54** may be provided to the apex **56** of the first liner portion **52**. As another non-limiting example, the second liner portion **54** may be provided along the skirt of the first liner portion **52**. As such, the second liner portion **54** may extend along at least a portion of the skirt section **58** (e.g., only a portion or the entire skirt section **58**). As another non-limiting example, the second liner portion **54** may be provided along both the skirt section **58** and the apex **56**.

[0058] In some embodiments, assembling the second liner portion **54** and the first liner portion **52** may include providing the first liner portion **52** onto the first outer surface **67** of the explosive component **46**. Alternatively, assembling the second liner portion **54** and the first liner portion **52** may include providing the first liner portion **52** onto the first outer surface **67** of the second liner portion **54**.

[0059] At least in some instances, one or more of the blocks **82**, **84**, and **86** of the process **80** may be omitted or combined. For example, in some embodiments, the second liner portion **54** may be formed using the first liner portion **52** such that effectively no separate assembly step may be performed. For example, the first liner portion **52** may be used as a form, die, molding, or tooling to form the second liner portion **54**. As such, the second liner portion **54** may be provided as an adjoined composite liner to the first liner portion **52**, based on the existing shape of the first liner portion **52**. In this way, the process **80** may generally include blocks **82** and **84**, while block **86** is omitted since the second liner portion **54** is formed using the first liner portion **52** as a form, die, mold, or tooling.

[0060] Accordingly, the present disclosure relates to a multi-part shaped charge liner **50**. In general, the multi-part shaped charge liner **50** includes two or more material powders or metal powder mixtures that may have a variable average green density after pressing. The multi-material shaped charge liner **50** may include different types of symmetries (e.g., axial symmetry (e.g., symmetry about the axis **72**), planar symmetric (e.g., symmetric about a plane perpendicular to the axis **72**), doubly planar symmetry (e.g., having multiple regions that are symmetric about a respective plane that is perpendicular to the axis **72**)) that provide a different shaped jet. For example, a planar symmetric mass distribution may provide a fan-line cutting jet upon detonation. In any case, the multi-part shaped charge liner **50** may be composed of materials other than powders, such as machine metal parts, injection molded plastic parts, ceramic parts, or a combination thereof. Further, the multi-part shaped charge liner **50** could be axisymmetric in geometry or have additional volume at the apex, skirt, or other region(s) which are planar symmetric, doubly planar symmetric, or symmetric on another period. For example, the multi-part shaped charge liner **50** may include a vary thickness that intrudes into the region either towards or away from the central axis.

[0061] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

[0062] The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for (perform)ing (a function) . . . ” or “step for (perform)ing (a function) . . . ”, it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

Claims

1. A shaped charge liner, comprising: a first liner portion formed of a first material, wherein the first liner portion comprises an apex and a skirt section that define an interior volume of the first liner portion; and a second liner portion formed of a second material, wherein the second liner portion is coupled to the first liner portion such that the second liner portion is an edge of the interior volume.
2. The shaped charge liner of claim 1, wherein the first material has a first green density and the second material has a second green density that is different than the first green density.
3. The shaped charge liner of claim 1, wherein the second liner portion is disposed adjacent the apex of first liner portion.
4. The shaped charge liner of claim 1, wherein the second liner portion is disposed adjacent the apex of the first liner portion and extends along a portion of the skirt section of the first liner portion.
5. The shaped charge liner of claim 1, wherein the first liner portion is formed of a first material, and the second liner portion is formed of a second material that is different than the first material.
6. The shaped charge liner of claim 1, wherein the first liner portion comprises a mixture of metals and non-metallic materials.
7. The shaped charge liner of claim 1, wherein the second liner portion comprises a planar symmetry.
8. The shaped charge liner of claim 1, wherein the shaped charge liner is a pressed component.
9. The shaped charge liner of claim 1, wherein the second liner portion is axially symmetric.
10. A shaped charge, comprising: a casing member; an explosive component positioned within an interior volume of the casing; and a multi-material liner coupled to the explosive component, wherein the multi-material liner comprises a first liner portion and a second liner portion, wherein the first liner portion is disposed between the explosive component and the second liner portion, and wherein the second liner portion is in contact with a surface of the first liner portion along an apex of the first liner portion.
11. The shaped charge of claim 10, wherein the second liner portion extends along 50% or less of a total length of a skirt portion of the first liner portion.
12. The shaped charge of claim 10, wherein a thickness of the second liner portion varies at different axial positions.
13. The shaped charge of claim 10, wherein the first liner portion includes a first material having a first green density, and wherein the second liner portion includes a second material having a second green density that is different than the first green density.
14. The shaped charge of claim 10, wherein the surface is an inner surface of the first liner portion.
15. The shaped charge of claim 10, wherein the second liner portion comprises a planar symmetry.
16. A method, comprising: forming a first shaped charge liner portion using a first material; forming a second shaped charge liner portion using a second material; and coupling the second shaped charge liner portion to a surface of the first shaped charge liner portion.
17. The method of claim 16, comprising providing the second shaped charge liner portion within an explosive component of a shaped charge.
18. The method of claim 16, comprising coupling the second shaped charge liner portion to an inner surface along an apex of the first shaped charge liner portion.
19. The method of claim 16, comprising coupling the second shaped charge liner portion to an outer surface of the first shaped charge liner portion.
20. The method of claim 16, wherein the first shaped charge liner portion and the second shaped charge liner portion do not substantially overlap.