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INTERVENING SHAPED CHARGE LINER

Abstract

The present disclosure relates to shaped charge. The shaped charge includes an explosive component having a first density and a first mechanical strength. The shaped charge also includes a liner member having a second density and a second mechanical strength. Further, the shaped charge includes an intervening liner member having a third density and a third mechanical strength. The intervening liner member is disposed between the explosive component and the liner member. The intervening liner member has one or both of: the third density being between the first density and the second density; and the third mechanical strength being between the first mechanical strength and the second mechanical strength.

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Background/Summary

BACKGROUND

[0001] The present disclosure generally relates to systems and methods for shaped charge liners having intervening liner members.

[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 statement 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. The shaped charge includes an explosive component having a first density and a first mechanical strength. The shaped charge also includes a liner member having a second density and a second mechanical strength. Further, the shaped charge includes an intervening liner member having a third density and a third mechanical strength. The intervening liner member is disposed between the explosive component and the liner member. The third density is between the first density and the second density, the third mechanical strength is between the first mechanical strength and the second mechanical strength, or both.

[0010] In one embodiment, the present disclosure is directed to a shaped charge. The shaped charge includes an explosive component having a first density and a first mechanical strength. The shaped charge also includes a liner member having a second density and a second mechanical strength. The shaped charge also includes an intervening liner member having a plurality of material layers. Each material layer of the plurality of material players has a density that is between the first density and the second density. Each material layer of the plurality of material players has a mechanical strength that is between the first mechanical strength and the mechanical strength. The intervening liner member is disposed between the explosive component and the liner member.

[0011] In one embodiment, the present disclosure is directed to a method. The method includes providing an intervening liner member for a shaped charge. The method also includes providing a primary liner member. Further, the method includes assembling the shaped charge such that the intervening liner member is disposed between the primary liner member and an explosive component of the shaped charge.

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 an intervening liner member disposed between an explosive component and a liner member of a shaped charge, 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 multi-layered intervening liner member disposed between an explosive component and a liner member of a shaped charge, in accordance with aspects of the present disclosure; and

[0022] FIG. **8** 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

[0023] 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.

[0024] 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.

[0025] 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. In any case, each jet produced from a shaped charge may have some variability in shape, power, speed, and so on. The variability between each jet (i.e., “shot-to-shot variation”) reduces the predictability during operation of shaped charges and, thus, can result in unexpected operations of the shaped charge, such as failing and/or incomplete piercing or severing of the wellbore.

[0026] Without wishing to be bound by theory, it is believed that one of the main influences of shot-to-shot variation and causes of jet breakup may be the result of the Rayleigh-Taylor (RT) instability. RT instability arises at the interface between two fluids of different density where the lighter fluid is pushing (e.g., normal pressure) against the heavier fluid. In the case of a shaped charge, RT instability occurs at the interface of the explosive component and liner member (i.e., which are substantially a fluid at the extreme pressures present inside a shaped charge). In particular, the explosive material of the explosive component has become a gaseous by-product and is now at high pressure acting to accelerate the liner member towards the central axis and into jet formation. Assuming that the properties of the explosive products are fixed, it is believed that the mechanical properties of the liner member that influence RT instability may be the mechanical strength and density of the liner member. For example, without wishing to be bound by theory, it is believed that a greater mismatch between the mechanical strength (e.g., a mechanical strength mismatch of 500 MPa or greater, 600 MPa or greater, 700 MPa or greater, or 800 MPa or greater) and/or the density (e.g., a density mismatch of 4 g/cc or greater, 5 g/cc or greater, 6 g/cc or greater) of the explosive component and the liner member) produces an RT instability that results in unexpected shot-to-shot variation. As discussed above, the liner members are predominantly pressed powder liners and, thus, may not have much strength in tension and have relatively limited strength at the onset of compaction (i.e., in relation the scale of the pressures applied). Further, particularly for deep penetrators, the powder mixture is near to the density of tungsten, which is highly dense; again the worst case.

[0027] Accordingly, the present disclosure relates to an intervening liner member that bridges a gap between the mechanical properties of the explosive component and the liner member. In general, the disclosed intervening liner member has physical properties that are between the physical properties of the explosive component and the liner member. The intervening liner member may be formed of certain thermoplastics (e.g., thermoplastic materials) and/or metal sheets or metal films. In some embodiments, the intervening liner member may be formed of one or more powdered metals (e.g., powdered metal mixtures). In certain embodiments, the intervening liner member may be a multi-layered intervening liner member formed of one or more different materials (e.g., thermoplastics and/or metal sheets or films). In such embodiments, the multi-layered intervening liner member may include a gradually increasing or decreasing density and/or strength. That is, each layer of the multi-layered intervening liner member (e.g., each layer may be referred to as an additional intervening liner member) may have an increasing density and/or strength from a first end of a first layer that couples the explosive component to a second end of a second layer that couples to the liner member. In this way, the differences in mechanical properties at the interface(s) between the explosive component and the liner member are reduced, thereby reducing the effect of RT instability. Accordingly, the disclosed intervening liner member may provide a shaped charge that has relatively less shot-to-shot variation as compared to conventional shaped charges.

[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** (e.g., primary liner member). 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 member **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 member **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 an intervening liner member (e.g., an intervening shaped charge liner) that bridges the gap between the mechanical properties (e.g., strength, density, and so on) between the explosive component **46** and the liner member **48**. To illustrate this, FIG. **6** shows a cross-sectional view of a shaped charge **20** having an intervening liner member **50** in accordance with the present disclosure. In some embodiments, the intervening liner member **50** may be formed of thermoplastics (e.g., polyacrylic acids (PAA), poly(methyl methacrylate) (PMMA), polyamides, polyether ether ketone (PEEK), polyethylene (PE). In some embodiments, the intervening liner member **50** may be formed a metal sheets or films.

[0042] As described above, the liner member **48** may be formed of packed, powered metals and, at least in some instances, non-metallic materials. The metals of the liner member **48** may include metals having a density of approximately 8 or greater grams per cubic centimeter (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. The explosive component **46** may be formed of relatively less dense oxidizers (e.g., carbon, KClO.sub.4, KClO.sub.3, KNO.sub.3, etc.), explosive materials, propellants, or a combination thereof. For example, the explosive component **46** may have a density of approximately 3 or less g/cc, 2.5 or less g/cc, 2.2 or less g/cc, 2.0 or less g/cc, 1.8 or less g/cc, and so on. In some embodiments, the explosive component **46** may have a density between approximately 1 to 3 g/cc, 1.5 to 3 g/cc, 1.8 to 3 g/cc, or 1.8 to 2.5 g/cc.

[0043] As such, the intervening liner member **50** may be formed of materials having a density that is between the density of the explosive component **46** and the liner member **48**. That is, the explosive component **46** may have a first density, the liner member **48** may have a second density, and the intervening liner member **50** (e.g., or one or more layers of the intervening liner member **50** as described in FIG. **7**) may have a third density between the first density and the second density. For example, the intervening liner member **50** may have a density between approximately 2.5 g/cc and 8 g/cc, 3 g/cc to 8 g/cc, 2.5 to 7 g/cc, 2.5 to 6 g/cc, 3 to 7 g/cc, 3 to 6 g/cc, or 3 to 5 g/cc. For example, the intervening liner member **50** may be formed of (e.g., include or consist essentially of) calcium, aluminum, barium, beryllium, or other metals having a relatively low density (e.g., less than 8 g/cc), such that the intervening liner member **50** has a third density that is between the first density of the explosive component **46** and the second density of the liner member **48**. For example, the intervening liner member **50** may include different combinations of amounts of metals described herein.

[0044] Additionally or alternatively, the intervening liner member **50** may have a mechanical strength that is between the mechanical strength of the explosive component **46** and the liner member **48**. That is, the explosive component **46** may have a first mechanical strength, the liner member **48** may have a second mechanical strength, and the intervening liner member **50** (e.g., or one or more layers of the intervening liner member **50** as described in FIG. **5**) may have a third mechanical strength between the first mechanical strength and the second mechanical strength. For example, the liner member **48** may have a mechanical strength (e.g., tensile strength and/or yield strength) that is greater than or equal to 300 Mega Pascals (MPa), greater than or equal to 400 MPa, greater than or equal to 500 MPa, greater than or equal to 600 MPa, greater than or equal to 700 MPa, greater than or equal to 800 MPa, greater than or equal to 900 MPa. The explosive component **46** may have a relatively lower mechanical strength than the liner member **48**, such as less than or equal to 100 MPa, less than or equal to 50 MPa, or less than or equal to 40 MPa. As such, the intervening liner member **50** may have a mechanical strength that is between approximately 40 MPa and 300 MPa, between approximately 40 MPa and 500 MPa, between approximately 40 MPa and 600 MPa, between approximately 50 MPa and 300 MPa, between approximately 50 MPa and 500 MPa, or between approximately 50 MPa and 700 MPa.

[0045] As shown in FIG. **6**, the intervening liner member **50** includes a generally conical shape having an apex **51** and a skirt section **52** (e.g., that gradually extends radially outward from the apex **51** to an axial end of the skirt section **52**, for example, relative to an axis **60**). The apex **51** and the skirt section **52** generally define the interior volume **44** (e.g., inner volume) of the intervening liner member **50** where the liner member **48** is disposed. The apex **51** and/or skirt section **52** of the intervening liner member **50** may generally complement the shape of a corresponding apex and skirt section of the liner member **48**. Although the illustrated embodiment of the intervening liner member **50** includes an apex **51**, it should be noted that in some embodiments the intervening liner member **50** may not include the apex **51**, and may only include the skirt section **52**. That is, the intervening liner member **50** may not completely cover the liner member **48**. Similarly, although the illustrated embodiment of the intervening liner member **50** includes the skirt section **52**, it should be noted that in some embodiments the intervening liner member **50** may not include the skirt section **52**, and may only include the apex **51**.

[0046] The intervening liner member **50** is generally disposed between the explosive component **46** and the liner member **48**. For example, and as shown, the intervening liner member **50** may physically couple to the explosive component **46** at a first end **53** (e.g., a first surface along the skirt section **52** and/or the apex **51**). Further, the intervening liner member **50** may physically couple to the explosive component **46** at a second end **54** (e.g., a second surface along the skirt section **52** and/or the apex **51**).

[0047] The intervening liner member **50** has a thickness **56**. In general, the thickness **56** may be relatively smaller than a corresponding thickness **58** of the liner member **48**. For example, the thickness **56** of the intervening liner member **50** may be 10% or less, 20% or less, 40% or less, 50% or less, 60% or less, or 70% or less, than the thickness **58** of the liner member **48**. It is presently recognized that it may be advantageous to adjust the thickness **56** and/or mass of the intervening liner member **50** such that the intervening liner member **50** is hydrodynamically equivalent to less than the total mass of the intervening liner member **50** and the liner member **48**. For example, the intervening liner member **50** may be hydrodynamically equivalent to less than or equal to 20%, less than or equal to 18%, less than or equal to 15%, less than or equal to 12%, or less than or equal to 10% of the total mass of the intervening liner member **50** and the liner member **48**. In some embodiments, the intervening liner member **50** may be hydrodynamically equivalent to between approximately 5 to 20%, between approximately 10 to 20%, between approximately 15 to 20%, or between approximately 10 to 15% of the total mass of the intervening liner member **50** and the liner member **48**.

[0048] As shown, the intervening liner member **50** extends along the portion **61** of a skirt section **62** of the liner member **48**. While the illustrated embodiment shows the skirt section **52** of the intervening liner member **50** extending along approximately the entire skirt section **62** of the liner member **48**, it should be noted that the skirt section **52** of the intervening liner member **50** may extend along any suitable portion of the skirt section **62** of the liner member **48**, such as 10% or less of the total length **64** of the skirt section **62**, 20% or less of the total length **64** of the skirt section **62**, 30% or less of the total length **64** of the skirt section **52**, 40% or less of the total length **64** of the skirt section **52**, 50% or less of the total length **64** of the skirt section **62**. However, in other embodiments, the skirt section **52** of the intervening liner member **50** may extend over a majority (e.g., greater than 50% of the total length of the skirt section **62**). For example, the skirt section **52** of the intervening liner member **50** may extend along 50% or greater of the total length **64** of the skirt section **62**, 60% or greater of the total length **64** of the skirt section **62**, 70% of greater of the total length **64** of the skirt section **62**, 80% or greater of the total length **64** of the skirt section **62**, 90% or greater of the total length **64** of the skirt section **62**.

[0049] In some embodiments, the intervening liner member **50** may include multiple layers. To illustrate this, FIG. **7** shows a cross-sectional view of a shaped charge **20** having an intervening liner member **50** with multiple layers **70**, **72**, and **74**, in accordance with the present disclosure. While three layers are shown, it should be noted that the intervening liner member **50** may include any number of layers, such as two layers, three layers, four layers, five layers, or more than five layers.

[0050] In a generally similar manner as described in FIG. **6**, the intervening liner member **50** includes a generally conical shape having an apex **51** and a skirt section **52**. That is, each layer **70**, **72**, and **74** may include a corresponding skirt section **52** and apex **51**. Further, it should be noted that in some instances, one or more of the layers **70**, **72**, and **74** may have only a skirt section **52**, only an apex **51**, or both. As such, rather than having a conical shape, the intervening liner member **50** may have a cylindrical shape.

[0051] The intervening liner member **50** is generally disposed between the explosive component **46** and the liner member **48**. In the illustrated embodiment, the first layer **70** is physically coupled to the explosive component **46** at a first end **53** (e.g., first side or first surface). Further, the third layer

74 is physically coupled to the liner member **48** at the second end **54** (e.g., a second side or second surface). The second layer **72** is disposed therebetween and coupled to each of the first layer **70** and the third layer **74**.

[0052] The first layer **70**, the second layer **72**, and the third layer **74** may be arranged in any suitable arrangement such that the difference in mechanical properties at the interface between the explosive component **46** and the liner member **48** is less than the difference in mechanical properties without the intervening liner member **50**. For example, the first layer **70**, the second layer **72**, and the third layer **74** may be arranged in order of increasing density along the direction **76** (e.g., from a position normal to a surface of the explosive component) that extends from the explosive component **46** to the liner member **48**. Additionally or alternatively, the first layer **70**, the second layer **72**, and the third layer **74** may be arranged in order of increasing mechanical strength along the direction **76**. In some embodiments, the second layer **72** or any further intervening layers between the first layer **70** and the third layer **74** (e.g., a fourth layer) may have a relatively higher density and/or mechanical strength than the first layer **70**, but less than the density and/or mechanical strength of the first layer **74** (e.g., the density may increase from the first layer **70** the second layer **72** and then decrease from the second layer **72** to the third layer **74**).

[0053] As illustrated in FIG. **7**, the intervening liner member **50** may have a thickness **56** (e.g., a total thickness) that is less than a thickness **58** of the liner member **48**. For example, the first layer **70** has a thickness **78**, the second layer **72** has a thickness **80**, and the third layer **74** has a thickness **82**. In some embodiments, one or more of the thicknesses **78**, **80**, and **82** may be equal. In some embodiments, the thicknesses **78**, **80**, and **82** may be different. For example, the thicknesses **78**, **80**, and **82** may generally increase in the direction **76**. Alternatively, the thicknesses **78**, **80**, and **82** may generally decrease in the direction **76**.

[0054] As shown, each of the layers **70**, **72**, and **74** extend along the total length **64** of the skirt section **62** of the liner member **48**. However, in some embodiments, one or more of the layers **70**, **72**, and **74** may extend along only a portion of the total length **64**, such as less than or equal to 90% of the total length **64**, less than or equal to 80% of the total length **64**, less than or equal to 70% of the total length **64**, less than or equal to 60% of the total length **64**, less than or equal to 50% of the total length **64**, or less than or equal to 40% of the total length **64**. In such embodiments where at least one layer of the layers **70**, **72**, and **74** do not extend along the entire total length **64**, one or more of the other layers **70**, **72**, or **74** may have an increased thickness **78**, **80**, or **82**.

[0055] FIG. **8** shows an example process **90** for forming the intervening liner member **50** in accordance with the present disclosure. As shown, the process **90** includes, at block **92**, providing an intervening liner member **50** having one or more layers. In some embodiments, block **92** may include arranging the layers in order of increasing density, increasing mechanical strength, or both. In some embodiments, providing the intervening liner member **50** may include forming the intervening liner member **50**. The intervening liner member **50** may be formed, manufactured, or otherwise applied by a variety of means such as for instance: sheet film, hot dipped, spray coated, pour formed, injection molded into a separate part then pressed as part for charge manufacturing, or formed as part of a multi-material liner whereby a powdered form of the intermediate material would first be pressed followed by subsequent layers of further intermediates or the main liner material. The multiple intermediates may be used such that each successive layer is nearer to the final composition of the liner member **48** and/or a target composition (e.g., a threshold density less than the density of the liner member **48**, a threshold mechanical strength less than the mechanical strength of the liner member **48**, or both), thereby producing a smoother transition.

[0056] The process **90** also includes, at block **94**, providing a liner member to the one or more layers of the intervening liner member **50**. In general, block **94** may include coupling the intervening liner member **50** to the second end **54** of the liner member **48**. Further, the process **90** includes, at block **96**, assembling the shaped charge **20** including the intervening liner member **50**. Block **96** may generally include coupling the intervening liner member **50** to the first end of the

explosive component **46** and/or providing the intervening liner member **50** into a shaped charge **20**.
[0057] Accordingly, the present disclosure relates to techniques for reducing shot-to-shot variation in shaped charges **20**. In general, the disclosed techniques include providing an intervening liner member **50** that includes a density and/or mechanical strength in between that of the liner member **48** and the explosive component **46** of the shaped charge **20**.
[0058] 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.
[0059] 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, comprising: an explosive component having a first density and a first mechanical strength; a liner member having a second density and a second mechanical strength; and an intervening liner member having a third density and a third mechanical strength, wherein the intervening liner member is disposed between the explosive component and the liner member, wherein one or both of: the third density is between the first density and the second density; and the third mechanical strength is between the first mechanical strength and the second mechanical strength.
2. The shaped charge of claim 1, wherein the intervening liner member is a thermoplastic material.
3. The shaped charge of claim 1, wherein the intervening liner member is a metal film or sheet.
4. The shaped charge of claim 3, wherein the intervening liner member consists essentially of calcium, aluminum, barium, or beryllium.
5. The shaped charge of claim 1, wherein the intervening liner member is hydrodynamically equivalent to less than or equal to 20 wt % of a total mass of the intervening liner member and the liner member.
6. The shaped charge of claim 1, wherein the intervening liner member is hydrodynamically equivalent to less than or equal to 10 wt % of a total mass of the intervening liner member and the liner member.
7. The shaped charge of claim 1, comprising an additional intervening liner member comprising a fourth density and a fourth mechanical strength, wherein the fourth density is between the first density and the second density, and wherein the fourth mechanical strength is between the first mechanical strength and the second mechanical strength.
8. The shaped charge of claim 1, wherein the third density of the intervening liner member is less than 8 g/cc.
9. The shaped charge of claim 1, wherein the third mechanical strength of the intervening liner member is less than 100 MPa.
10. A shaped charge, comprising: an explosive component having a first density and a first mechanical strength; a liner member having a second density and a second mechanical strength; and an intervening liner member comprising a plurality of material layers, wherein each material layer of the plurality of material players comprise a density that is between the first density and the second density, wherein each material layer of the plurality of material players comprise a mechanical strength that is between the first mechanical strength and the mechanical strength, and

wherein the intervening liner member is disposed between the explosive component and the liner member.

11. The shaped charge of claim 10, wherein the plurality of material layers are arranged in order of increasing density along a direction from the explosive component to the liner member.

12. The shaped charge of claim 10, wherein the plurality of material layers are arranged in order of increasing mechanical strength along a direction from the explosive component to the liner member.

13. The shaped charge of claim 10, wherein the intervening liner member is a metal film or sheet.

14. The shaped charge of claim 10, wherein the intervening liner member is hydrodynamically equivalent to approximately 10 wt % to 20 wt % of a total mass of the intervening liner member and the liner member.

15. The shaped charge of claim 10, wherein the intervening liner member is a thermoplastic material.

16. A method, comprising: providing an intervening liner member for a shaped charge; providing a primary liner member; and assembling the shaped charge such that the intervening liner member is disposed between the primary liner member and an explosive component of the shaped charge.

17. The method of claim 16, wherein the intervening liner member comprises a plurality of layers.

18. The method of claim 17, wherein providing the intervening liner member comprising forming the plurality of layers arranged in order of increasing density.

19. The method of claim 17, wherein providing the intervening liner member comprising forming the plurality of layers arranged in order of increasing mechanical strength.

20. The method of claim 16, wherein a thickness of the intervening liner member is less than a thickness of the primary liner member.
