DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO:

Attorney Docket No. 83420
Date: 18 November 2004

The below identified patent application is available for licensing. Requests for information should be addressed to:

PATENT COUNSEL
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 00OC, BLDG. 112T
NEWPORT, RI 02841

Serial Number 10/947,788

Filing Date 20 September 2004

Inventor Ricardo J. Cardoso

If you have any questions please contact Mark W. Homer, Patent Counsel, at 401-832-6679.

Attorney Docket No. 83420
Customer No.: 23523

SHOCK LOADING TECHNIQUES FOR COMPOSITES

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT RICARDO J. CARDOSO, citizen of the United States of America, employee of the United States Government and resident of Pawtucket, County of Providence, State of Rhode Island, has invented certain new and useful improvements entitled as set forth above, of which the following is a specification:

MARK HOMER, ESQ.
Reg. No. 41848
Naval Undersea Warfare Center
Division Newport
Newport, RI 02841-1708
TEL: 401-832-6679
FAX: 401-832-1231

Attorney Docket No. 83420

SHOCK LOADING TECHNIQUES FOR COMPOSITES

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

BACKGROUND OF THE INVENTION

(1) Field Of The Invention

The present invention relates to evaluating properties of composites, and in particular to a method and an apparatus for simulating the effects of a shock wave on an air-backed composite.

(2) Description Of The Prior Art

The issue of using composites in naval applications has drawn recent attention with the emphasis of external payloads in the submarine community. New Design concepts call for external (to pressure hull) pods or weapon magazines. In order to maximize the useful payload, maintaining the magazine weight to a minimum is essential. A typical approach is to use high strength, lightweight materials, such as composites. The use of composites for critical applications such as external pod stowage is very important to the submarine community because of its strength-to-weight ratio. However under certain loading conditions such as underwater explosion shock, the possibility exists that implosion can occur, which may result in ship damage.

The design-for-depth issue has been studied extensively and is well understood and addressed by current design methods. However, when shock loading is considered, current methods cannot be used. Use of current "shock" design methods would yield composite sections that are significantly larger than required to meet the design criteria.

The desire to more accurately design these structures and sections to meet these harsh environments of explosive shock loading has lead to developing mathematical models of the composite. In many cases the mathematical models are used for simulation of shock loading. However, all mathematical models, static or dynamic require actual material properties to model the material for better accuracy. Ideally, dynamic data for dynamic simulations and static data for static simulations are used. In many cases, however, dynamic data is derived from static data through some empirically determined relations such as the Cowper-Symonds relation. It merits noting that although some mathematical relations do use actual dynamic data, the data is gathered from very low strain rate tests unlike those purposed in this application. The low strain rate data is not representative of actual shock since the loading rates are much higher under shock loading conditions. Such high strain rate loading conditions can be simulated using an experimental technique called the Split Hopkinson Pressure Bar (SHPB).

Review of published literature has shown that most of the works done in the area of shock impingement on submerged composite shells were primarily done using various mathematical techniques or Finite Element models. Some of the published studies were experimental in nature, however they used dynamic methods that had much lower strain rates than SHPB.

SUMMARY OF THE INVENTION

The present invention features a method of determining the dynamic shock loading response of a composite. The method includes first inducing a shock into the composite, measuring a response history of the composite, and determining a dynamic stress-strain response as a function of time using the measured reflected and transmitted strains. In a preferred embodiment, the composite is placed between a first end of an incident bar and a first end of a transmitter bar. The incident bar and the transmitter bar preferably include at least one strain gauge each. The shock is transmitted through the incident bar into the composite. The shock may be induced by moving a striker bar against a second end of a transmitter bar. Alternatively, the shock may be induced by igniting an explosive charge proximate the second end of the transmitter bar. The compressive stress pulse, tensile pulse, and transmitted pulse are measured as a function of time by the strain gauge disposed on the incident bar and transmitter bar. The dynamic stress-strain response is determined as a function of time using the measured reflected and transmitted strains by using the following relationships:

$$\varepsilon_s(t) = \frac{-2c_b}{l_s}\int_o^t \varepsilon_r(t)dt \quad (1)$$

$$c_b = \sqrt{\frac{E_b}{\rho_b}} \quad (2)$$

$$\sigma_s(t) = E_b \frac{A_b}{A_s}\varepsilon_t(t) \quad (3)$$

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood in view of the following description of the invention taken together with the drawings wherein:

FIG. 1 is a plan view of an exemplary embodiment of a Split Hopkinson Pressure Bar (SHPB) arrangement having a striker bar according to the present invention;

FIG. 2 is a plan view of an exemplary embodiment of a SHPB arrangement having an explosive change according to the present invention; and

FIG. 3 is a diagram of a typical stress-strain history measured by the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The upcoming section details the SHPB technique for the compressive arrangement. The underlaying wave theory is the same or similar for the tensile and torsional techniques, and therefore are omitted for the sake of brevity.

The present invention allows the dynamic stress-strain behavior of the material to be investigated using the Split Hopkinson Pressure Bar (SHPB) technique in compression, tension, torsion and shear. The typical compressive SHPB setup is shown in FIG. 1. The other SHPB types (tensile, torsional) are similar in nature except for loading direction and are within the knowledge of one skilled in the art. For shear, the specimen geometry is modified but the apparatus is the same as for the compression test.

Referring to FIGS. 1-3, the compressive SHPB system 10 comprises an incident bar 12 and transmitter bar 14, preferably both bars 12 and 14 are made of a material that is slightly harder than the specimen 20 being tested so transfer of a shock or compressive stress pulse C1 through the bars 12 and 14 do not destroy the specimen 20. Preferably, the bars 12 and 14 are also made of the same material. This reduces the variables in the equations used to determine properties discussed below. For example, in the case of a composite specimen 20 the bars 12 and 14 could be made of a steel material. The cross-sectional area of the bars 12 and 14 should be greater or equal to the cross-sectional area of the specimen 20 so that all of the compressive stress pulse C1 is transferred through incident bar 12 to the specimen 20. It is preferred that the cross-sectional areas of bars 12 and 14 are equivalent to reduce the variables in the equations discussed below. The bars 12 and 14 are instrumented with one or more strain gages 16,18 respectively. The specimen 20 is sandwiched between a first end 11 of the incident bar 12 and a first end 15 of the transmitter bar 14. A striker bar 22 is positioned proximate to a second end 13 of incident bar 12. Moving the striker bar 22 against the second end 13 transmits a compressive stress pulse C1 through the incident bar 12. Alternatively, an explosive charge 24, FIG. 2, can be used in place of the striker bar 22 shown in FIG. 1 to generate the compressive stress pulse C1.

In practice, the striker bar 22 or the explosive charge 24 generates a compressive stress pulse C1, as shown in FIG. 3, of a finite length into the incident bar 12. Upon reaching the specimen 20 a portion of the stress pulse gets reflected back as a tensile pulse T and a portion of the stress pulse C2 gets transmitted through the specimen 20 into the transmitter bar 14. The time resolved strain histories are recorded by a data acquisition module 26 and later used for analysis.

The dynamic stress-strain response 30, FIG. 3, of the specimen 20 can be obtained from the recorded strain histories using one dimensional wave propagation theory. Assuming homogeneous specimen deformation, the stress and strain ($\sigma_{si,}$ τ_s) in the specimen 20 can be generated as a function of time t from the measured reflected and transmitted strains (ϵ_r, ϵ_t) using the relations shown in the below equations:

$$\varepsilon_s(t) = \frac{-2c_b}{l_s}\int_o^t \varepsilon_r(t)dt \qquad (1)$$

$$c_b = \sqrt{\frac{E_b}{\rho_b}} \qquad (2)$$

$$\sigma_s(t) = E_b \frac{A_b}{A_s}\varepsilon_t(t) \qquad (3)$$

Where A_b is the cross-sectional area of the bars 12, 14 (assuming the bars comprise the same cross-sectional area), A_s is the cross-sectional area of the specimen 20, l_s is the specimen 20 length, c_b is the wave speed in the bar material and E_b and ρ_b are the Young's modulus and density of the bar 12, 14 material respectively (assuming that the bars 12 and 14 are made of the same material). Cylindrical specimens with a maximum diameter less than that of the SHPB bars and thickness to be determined by a relation not shown, can be used to obtain the dynamic stress strain profile of the material, thereby giving the maximum dynamic yield stress in compression.

In light of the above, it is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

Attorney Docket No. 83420

SHOCK LOADING TECHNIQUES FOR COMPOSITES

ABSTRACT OF THE DISCLOSURE

The dynamic stress-strain of composite materials may be determined using Split Hopkinson Pressure Bar (SHPB) techniques. The method includes placing a composite between a first end of an incident bar and a first end of a transmitter bar. Next, a shock is induced proximate a second end of the incident bar. The shock may be induced by striking the second end with a striker bar or igniting an explosive proximate the second end of the incident bar. Next, the reflected and transmitted strain is measured as a function of time using at least one gauge disposed on each of the incident and transmitter bars. The dynamic shock loading response of the composite is measured using the measured reflected and transmitted strain.

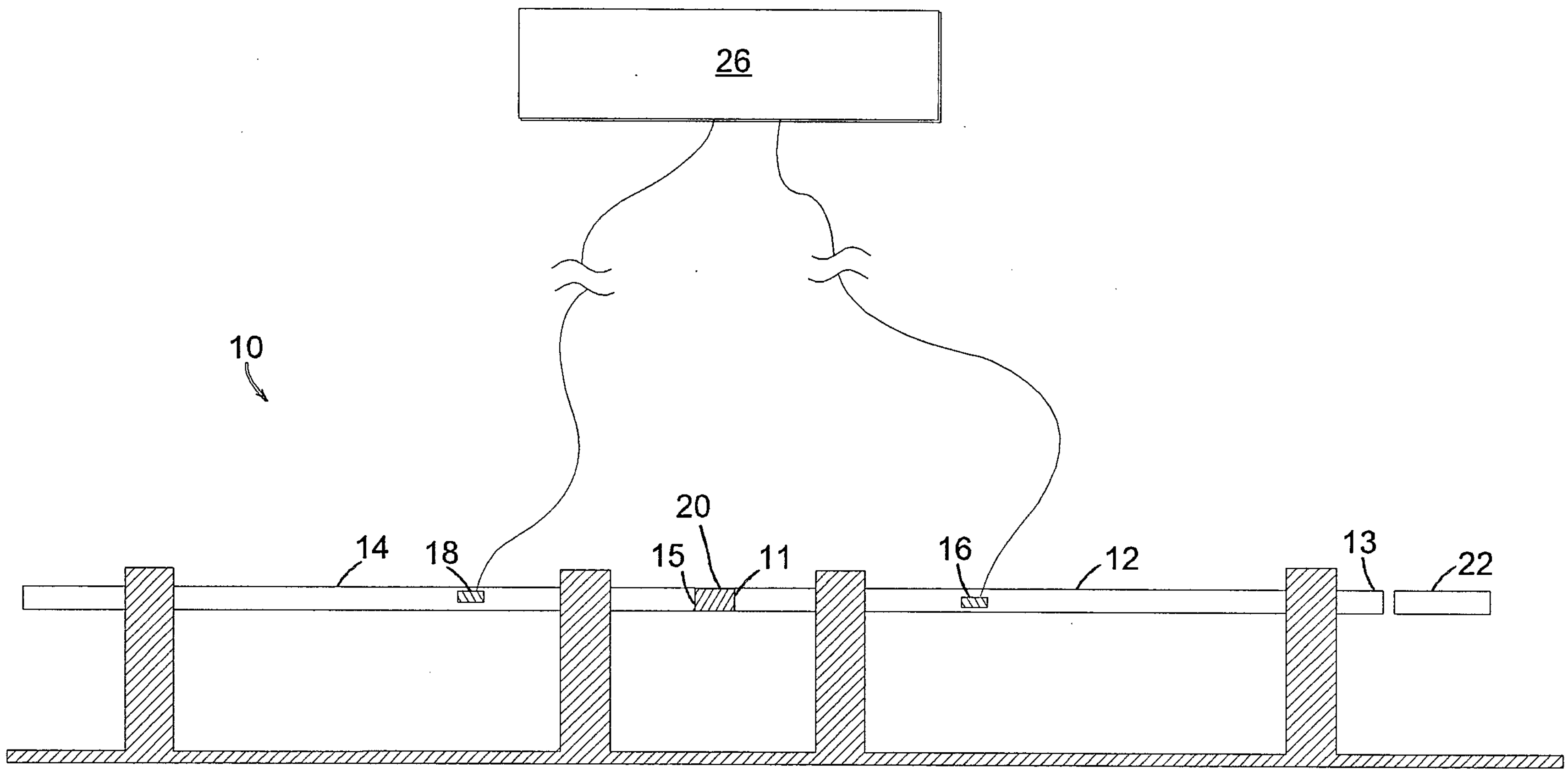

FIG. 1

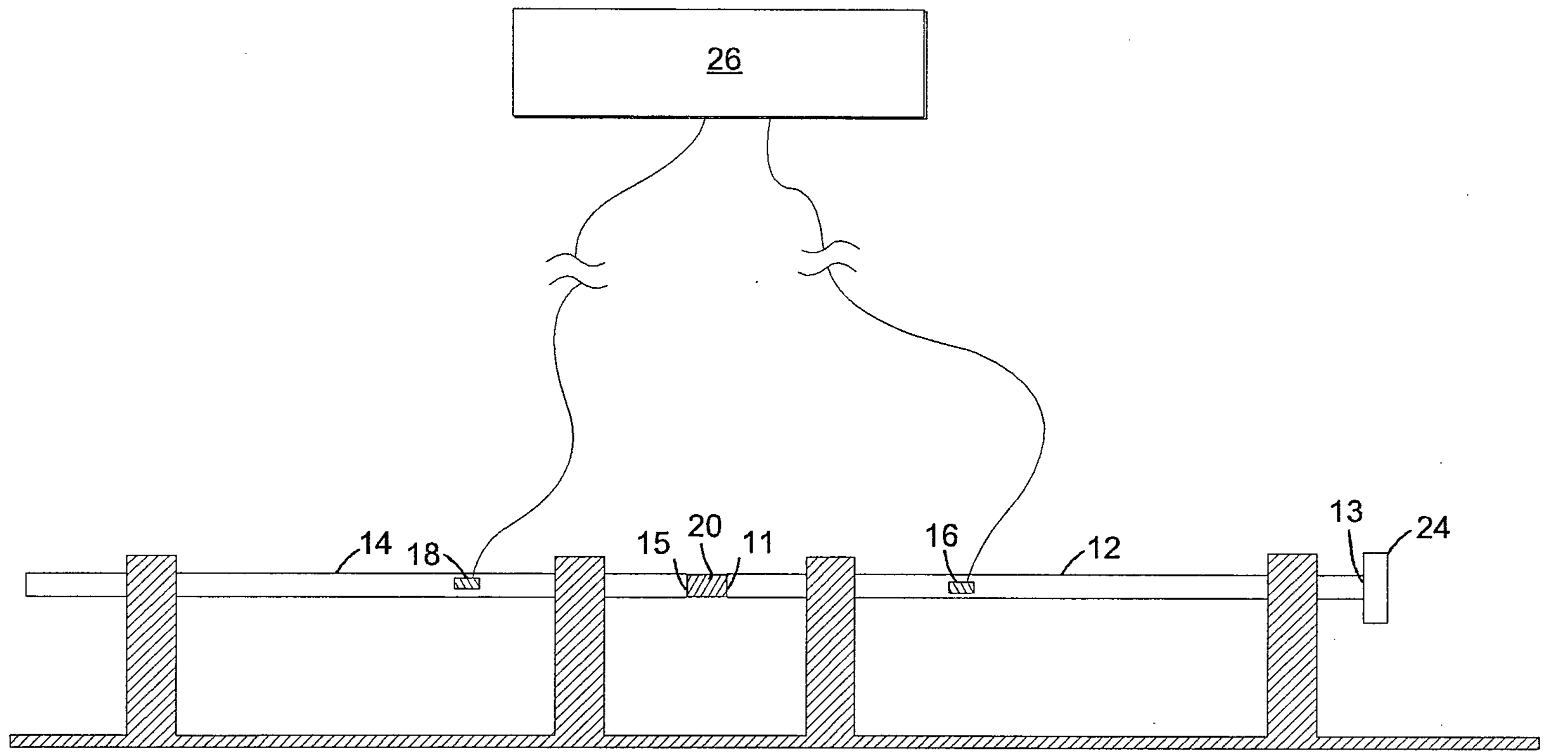

FIG. 2

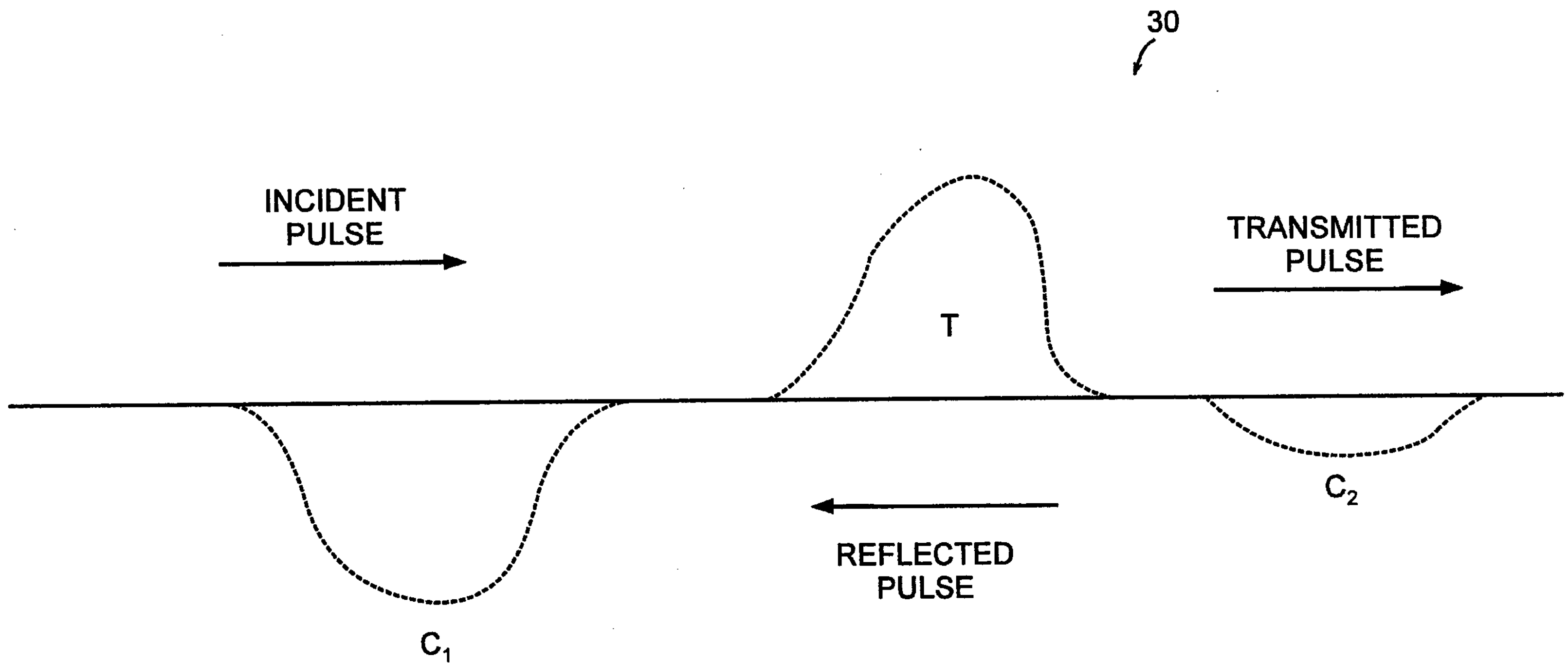
30
INCIDENT PULSE
T
TRANSMITTED PULSE
REFLECTED PULSE
C_1
C_2

FIG. 3