# United States Patent

**Huber et al.**

[15] **3,645,803**

[45] **Feb. 29, 1972**


## [54] METHOD FOR IMPROVING THE FRACTURE TOUGHNESS OF METALS AND ALLOYS


[72] Inventors: **Ralph W. Huber,** College Park; **William S. Pellini,** Forest Heights; **Robert J. Goode,** Bowie, all of Md.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy**



[22] Filed: **Apr. 16, 1970**

[21] Appl. No.: **29,193**

[52] **U.S. Cl.** ..... **148/127,** 29/198, 29/497.5, 29/504, 148/32, 147/34, 148/133

[51] **Int. Cl.** ..... **C21d 1/00,** B23p 3/09

[58] **Field of Search** ..... 29/194, 198, 504, 497.5; 75/175.5; 148/127, 32, 34, 133



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,804,409 | 8/1957 | Kessler et al. | 75/175.5 X |
| 3,025,592 | 3/1962 | Fischer et al. | 29/194 |
| 3,070,881 | 1/1963 | Brooks et al. | 29/504 |
| 3,137,937 | 6/1964 | Cowan et al. | 29/504 X |

FOREIGN PATENTS OR APPLICATIONS

| | | | |
|---|---|---|---|
| 822,750 | 10/1959 | Great Britain | 29/198 |

OTHER PUBLICATIONS

Titanium Abstract Bulletin, Brooks et al., Elastic Moduli and Tensile Properties of Titanium Carbon and Titanium Aluminum-Carbon Alloys page 300 Abstract No. 3326, 1958.



*Primary Examiner*—Charles N. Lovell

*Attorney*—R. S. Sciascia, Arthur L. Branning, J. G. Murray and M. L. Crane



[57] **ABSTRACT**

This invention is directed to a method of improving the fracture toughness of titanium alloys by bonding a high-strength alloy of normally low toughness onto a lower strength alloy of high fracture toughness with subsequent heat treatment of the combination if desired or required.


**3 Claims, 4 Drawing Figures**

PATENTED FEB 29 1972

3,645,803

SHEET 1 OF 2

FIG. 2

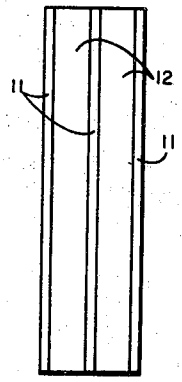



FIG. 1

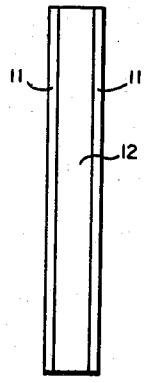
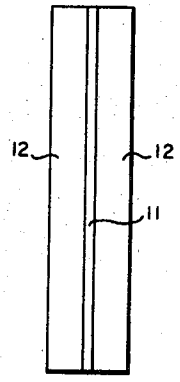



FIG. 3




INVENTORS
ROBERT J. GOODE
RALPH W. HUBER
WILLIAM S. PELLINI
BY Melvin L. Crane, AGENT
ATTORNEY

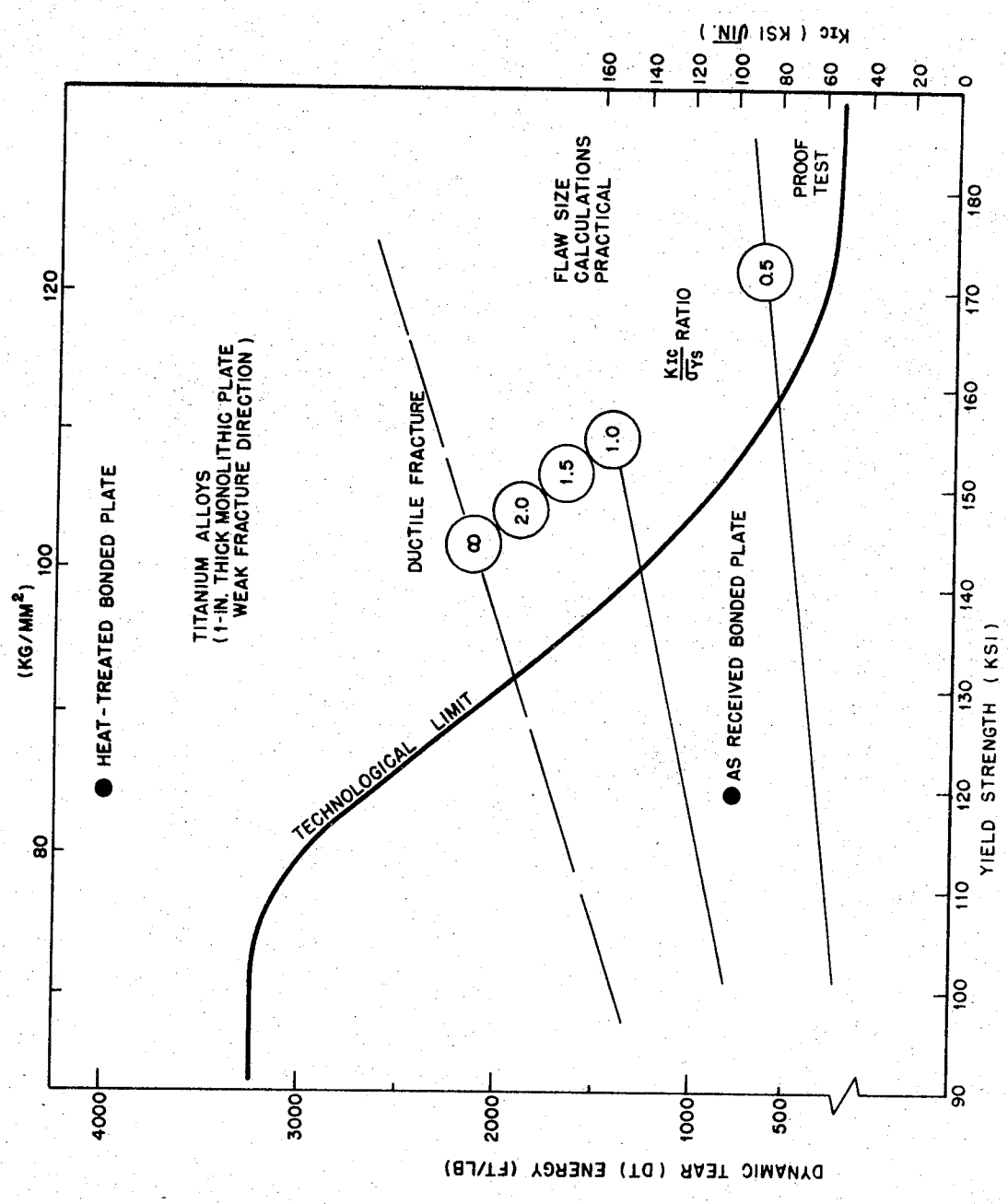



FIG. 4

INVENTORS
ROBERT J. GOODE
RALPH W. HUBER
WILLIAM S. PELLINI
BY Melvin L Crano AGENT
ATTORNEY

# METHOD FOR IMPROVING THE FRACTURE TOUGHNESS OF METALS AND ALLOYS

## 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 therefor.

## BACKGROUND OF THE INVENTION

Heretofore, metals have been bonded to structures for various reasons. Lower strength materials have been bonded with high-strength materials to increase their usable strength. Nonoxidizable metals have been bonded to oxidizable metals for environmental protection. Expensive metals have been bonded onto inexpensive metals. Bonding has been used for improved wear, for improved temperature resistance, for looks and many other reasons.

Aluminum, titanium, and other metals have been treated to change their characteristics for various reasons. Attainment of improvements in fracture toughness for titanium and other alloy systems has followed the characteristic metallurgical practices. Development of new and modification of existing alloy compositions and development of optimum melting, forging, rolling and heat treatment practices for particular alloys have all been previously used. High-strength titanium alloys have been obtained by combining titanium with suitable alloying elements during melting and by use of solution heat treatments at various temperatures, quenching, and subsequently aged at various temperatures. The time required for solution heating and aging depends on the thickness and composition of the alloy being treated. Strength level and fracture toughness is different for different materials and different conditions, however, an upper limit of fracture toughness has been defined. This limit line, termed the Technological Limit Line (previously termed the Optimum Material Trend Line), reflects the best material for current technology, and it shows a general decrease in fracture toughness with increasing strength level.

Fracture toughness of a metal is defined as a measure of the ability of the metal to resist the initiation and propagation of a crack or fracture. Fracture toughness is dependent upon a number of metallurgical factors which include the purity of the base metals, alloy composition, interstitial impurities, melting practice, solidification rates, forging procedures, hot rolling (temperature reduction rate and direction of rolling), and the final heat-treating schedules.

## SUMMARY OF THE INVENTION

This invention is directed to a method of improving the fracture toughness of titanium alloys by bonding an alloy of one high fracture toughness and low strength to an alloy of high strength and low fracture toughness. The fracture toughness of a metal, herein defined as a measure of the ability of a metal to stop a running crack or fracture, is dependent upon several factors. These factors include the following: the purity of the base metal, alloy composition, interstitial impurities, melting practice, solidification rates, forging procedures hot rolling (temperature, reduction rate, and direction of rolling), and the final heat-treating schedules. These factors are all important considerations for optimizing the strength and fracture toughness properties. The fracture toughness limit line as set forth in the prior art can shift to higher levels of strength and toughness as improvements in materials are achieved. This invention brings about a significant increase in toughness with little loss in overall yield strength which substantially exceeds the current technology for monolithic plate of 1-inch thickness as defined by Technological Limit Line. Thus, this invention represents a breakthrough or technological advance in the development of titanium alloys of high fracture toughness.



## STATEMENT OF THE OBJECTS

Generally, an object of this invention is to provide an improvement in high-strength titanium alloys for use in structural applications.

Another object of the present invention to increase the fracture toughness of titanium alloys significantly above that of the current technology for monolithic plate as defined by the Technological Limit Line.

Still another object is to provide a method for improving the combined strength and fracture toughness characteristics of a titanium alloy.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates a composite structure formed by a titanium alloy of high fracture toughness and low strength bonded with an alloy of low strength and high fracture toughness.

FIG. 2 illustrates a composite structure formed by bonding a plate of titanium alloy of high fracture toughness and low strength onto each side of a pair of titanium alloy of high strength and low fracture toughness.

FIG. 3 illustrates a composite structure formed by bonding a plate of titanium alloy of high fracture toughness and low strength between two plates of titanium alloy of high strength and low fracture toughness.

FIG. 4 illustrates a ratio analysis diagram for high-strength titanium alloys.

In carrying out one form of the invention represented by FIG. 1, a titanium alloy plate 11 containing Ti–3.5Al is bonded onto each side of a titanium plate 12 containing Ti–4Al–3Mo–1V by any suitable cladding method such as an explosive bonding process developed by the DuPont Company and known as "Deta clad." (The numerical values included in the alloy content are nominal percent by weight of the metal included.) The plate sandwich forms a coplanar macrocomposite of about one inch in thickness in which the cladding represents about 12 percent of the overall thickness. A Dynamic Tear test of the "as-clad" 1-inch plate required a fracture of about 750 ft.-lb. Dynamic Tear energy for fracture in the weakest direction and a Dynamic Tear energy for fracture of about 1,870 ft.-lb. in the strongest fracture direction.

The composite cladded plate was solution annealed in a vacuum furnace at a temperature near the Beta transus for 1 hour rapidly cooled by water quenching and aged at 1,200° F. for 2 hours. After the annealing, water quench, aging process, the composite plate was tested using the same Dynamic Tear test previously used on the untreated plate and the Dynamic Test values were increased to about 3,970 and 6,600 ft lb. (not shown) for fracture in the weakest and strongest fracture direction, respectively, as shown in FIG. 4. Thus, the test clearly shows a marked increase in fracture toughness. This increase in toughness at a 0.2 percent offset yield strength of 119.8 Ks.i. significantly exceeds the Technological Limit for monolithic plate of 1 inch thickness.

It will be obvious to one skilled in the art, that a composite structure may be made as shown in FIG. 2, which illustrates a thin plate of a titanium alloy 11 of high fracture toughness and low strength bonded onto the outside and between a pair of plates of titanium alloy of high strength and low toughness 12. Such a structure improves the fracture toughness to be greater than that of the structure of FIG. 1, and the fracture toughness is much greater than the "as purchased" titanium alloy without the bonded thin plates.

FIG. 3 illustrates a composite structure with a plate 11 of titanium alloy of high fracture toughness and low strength bonded between separate plates 12 of titanium alloy having high strength and low fracture toughness.

FIG. 4 illustrates a Ratio Analysis Diagram (RAD) for high-strength titanium alloys. Increasing Dynamic Tear (DT) and $K_{Ic}$ values signify an increasing level of fracture toughness. The Technological Limit line denotes the highest attainable level of fracture toughness with respect to yield strength for

as-produced as well as for heat-treated titanium alloys in the form of 1-in. thick monolithic plate.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. A method of improving the fracture toughness of titanium alloy which comprises,

bonding at least one plate of high fracture toughness and low-strength titanium alloy consisting of 3.5 percent Al and the balance titanium onto a plate of low frature toughness and high-strength titanium alloy consisting of 4% Al 3% Mo, 1% V and the balance titanium,

solution annealing said bonded composite structure,

water quenching said solution annealed bonded composite structure and

aging said water quenched bonded composite structure at a temperature and for a time sufficient to improve the fracture toughness of said composite structure.

2. A method as claimed in claim 1; wherein,

said composite structure is solution annealed in a vacuum at a temperature near the Beta transus for 1 hour followed by water quenching and aging at about 1,200° F. for 2 hours.

3. A method as claimed in claim 2; wherein,

said bonding is carried out by an explosive bonding method.

* * * * *