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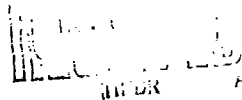
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SUMMARY

of

PERSONNEL ARMOR MATERIALS SYMPOSIUM

19, 20 SEPTEMBER 1957



QUARTERMASTER RESEARCH & ENGINEERING CENTER
CHEMICALS AND PLASTICS DIVISION

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SEPTEMBER 1958

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HEADQUARTERS QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, US ARMY
Quartermaster Research and Engineering Center
Natick, Massachusetts

CHEMICALS AND PLASTICS DIVISION

SUMMARY OF PERSONNEL ARMOR MATERIALS SYMPOSIUM

19, 20 September 1957

Compiled by

Anthony L. Alesi

Protective Materiel Branch

Project Reference:
7-80-35-001

September 1958

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FOREWORD

The exchange of information among investigators working on different problems in the same broad area is unfortunately sometimes incomplete, often infrequent, and seldom prompt. Where the area involved is under a security classification, there is even less than the usual amount of information exchanged. When the investigators are in independent private laboratories and in quasi-independent government laboratories linked only through contractual and administrative relationships and separated physically, there is a great possibility that each investigator may conduct his work in comparative isolation from the others.

This report summarizes the proceedings of an attempt to facilitate the necessary and important exchange of information among a small group of investigators from the Quartermaster Research and Engineering Center and from private organizations under contract to the Quartermaster Research and Engineering Command concerned with the development of materials for personnel armor. It was the consensus of those attending that the two-day informal symposium did result in the hoped-for exchange of information. Furthermore, there were other important results. Investigators working under contract became better aware of the broad outline of the field of interest to the QM R&E Command, and of the specific problems now under study. Contacts were established between investigators from the various private laboratories represented. The meeting stimulated ideas to be brought back for consideration and testing. Finally, an opportunity for free discussion was provided for each representative to state, criticize, and defend his ideas and those of his colleagues; in short, this symposium provided the opportunity for subjecting information and ideas to the critical analysis of the group.

The success of the symposium, as evidenced by the participants' expressions of interest and requests for future meetings, leaves no doubt that meetings of this kind are both desirable and worthwhile. In the future, a symposium on personnel armor materials will be held periodically. A similar symposium is planned on helmet and body armor design and fabrication problems. It is further hoped that these meetings can be expanded to include participation by other interested government agencies.

GEORGE R. THOMAS, Ph.D..
Chief
Chemicals and Plastics Division

Approved:

CARL L. WHITNEY, Lt. Col., QMC
Commanding Officer
QM R&E Center Laboratories

A. STUART HUNTER, Ph.D.
Scientific Director
QM Research & Engineering Command

CONTENTS

	<u>Page</u>
Abstract	iv
Introduction	1
Symposium Agenda	2
Identification of Speakers, Laboratories and Contracts	5
Papers Presented	7
Recommendations	18
Acknowledgments	18
Distribution List	

ABSTRACT

The proceedings of the Personnel Armor Materials Symposium held at the Quartermaster Research and Engineering Center on 19,20 September 1957 are presented. Participants were those personnel of the Center and of organizations under contract to the QM R&E Command engaged in the development of materials for personnel armor. Summaries of the eleven papers delivered at the symposium are presented. Recommendations are made for the greater use of symposia for personnel in many government laboratories and government contractor laboratories, who are active in conducting investigations, to facilitate exchange of information and ideas.

SUMMARY OF PERSONNEL ARMOR MATERIALS SYMPOSIUM
19, 20 September 1967

INTRODUCTION

The Quartermaster Corps has Department of the Army responsibility for the development and procurement of personnel armor. The Quartermaster Research and Engineering Command is assigned the research and development activities under Project 7-80-05-001, Personnel Armor. At the QM R&E Center, work is conducted as a team project involving all five operating Divisions, with the Chemicals and Plastics Division as the project leader.

At a monthly technical meeting of Center personnel engaged in this project, Mr. Theodore L. Bailey suggested that the Command's contractors working on personnel armor be invited to a meeting wherein both the contractor and Center personnel could exchange information and discuss ideas. This suggestion was enthusiastically endorsed by the group.

The nature of the meeting was determined by the realization that, in order to accomplish its objective of promoting the exchange of information and the discussion of ideas, the meeting should be kept small and quite informal. Accordingly, the first meeting was restricted to the subject of materials for personnel armor. A two-day meeting was believed desirable in order to allow sufficient discussion time. Further meetings are planned to discuss body armor design and fabrication problems.

The physical arrangements for the meeting were selected to enhance the informal atmosphere considered desirable for the success of the meeting. The QMREC Officers Club lounge was selected rather than a large conference room or the Center auditorium.

Invitations were sent to Command contractors concerned with materials for personnel armor and all accepted.

SIMPOSIUM AGENDA

The prepared agenda was followed except for a change in the order of the speakers for the afternoon of the first day and the elimination of the tour scheduled for the second afternoon to allow additional discussion time. The agenda followed is given herein.

HEADQUARTERS QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, US ARMY
QUARTERMASTER RESEARCH AND ENGINEERING CENTER
NATICK, MASSACHUSETTS

ARMOR MATERIALS SYMPOSIUM

19, 20 September 1957

AGENDA

Thursday, 19 September 1957

Welcome (1000 - 1005)

Dr. J. F. Oesterling

QMR&E Armor Program (1005 - 1020)

Mr. M. I. Landsberg
(Chairman)

Presentations

1. QMR&E Center (1020 - 1120)

- a. The development of multiphasic armor constructions.

Mr. A. L. Alessi

(Armor structures consisting of two or more dissimilar materials are discussed. A suggested method of selecting materials to construct a multiphasic structure is presented.)

- b. Energy absorption of single layer and composite armor structures.

Mr. A. S. Tente

(The variation in energy absorption of various armor materials, when impacted by two sizes of fragment simulators at various velocities, is discussed. The application of energy absorption studies on materials in composite panels is demonstrated.)

2. Polaroid Corporation (1120 - 1220)

- a. Scope of program.

Dr. W. A. Shurcliff

- b. Some ballistic properties of UN-39 platen. Mr. E. S. Emerson
- c. Importance of type and extent of parallelism among organic polymeric molecules comprising an armor panel. Dr. W. A. Shurecliff
- d. Applicability of dynamic photoelastic analysis to the study of impact phenomena. Mr. E. S. Emerson

Lunch (1230)

3. Rutgers University (1330 - 1430)

Properties of technical ceramics. Mr. E. J. Smoke

(Discussion of the unique engineering properties of ceramics, for example, refractoriness and other thermal properties, mechanical strength, hardness, chemical durability.)

4. Bjorksten Research Labs., Inc. (1430 - 1530)

Measurement of the energy absorption characteristics of materials as a function of projectile velocity. Mr. E. A. Meyer

(Discussion of the cause and elimination of a major source of error in velocity measurements with lumiline screens. Energy absorption measurements will also be presented on materials tested to date.)

Discussion (1530 - 1700)

New approaches to the development of armor materials and material systems.

Friday, 20 September 1957

Presentations

1. U. S. Army Chemical Warfare Laboratories (0900 - 1100)

- a. Technique for determining strain history of yarns under high-speed impact. Mr. J. W. Jamieson

(Discussion of apparatus, techniques and instrumentation for obtaining on a photograph the complete history of the strain distribution in a single yarn when impacted transversely at high speeds. Photographs obtained with rotating mirror apparatus will be discussed.)

- b. A new technique for determining transient deformation.

Mr. G. M. Stewart

(A photographic study of the dynamics of body armor materials under high-speed impact using a multiflash unit for the light source. Results of studies of impacted helmet, cloth and yarn, and secondary missile effect from impacted protective lenses will be discussed.)

2. Battelle Memorial Institute (1100 - 1200)

Development of titanium alloys under Quartermaster contract.

Mr. A. M. Sabroff

Lunch (1230)

Discussion (1330 - 1500)

New approaches to the development of armor materials and material systems.

Tour (1500 - 1630)

IDENTIFICATION OF SETBACKS, LABORATORIES AND CONTRACTS

QM R&E Command

Dr. J. Fred Oesterling, Deputy Scientific Director

QM R&E Center

Project 7-80-05-001, Personnel Armor

Participating Divisions: Chemicals & Plastics (Project Leader)
Environmental Protection Research
Mechanical Engineering
Pioneering Research
Textile, Clothing & Footwear

Speakers: Mr. M. I. Landenberg, Chief, Personnel Armor Section
Chemicals & Plastics Division
Mr. A. L. Alesi, Technologist (Plastics)
Chemicals & Plastics Division
Mr. A. S. Tente, Mechanical Engineer (Textiles)
Textile, Clothing & Footwear Division

Polaroid Corp., Cambridge, Mass.

Contract DA19-129-QM-209 "Investigation of the Mechanism of Energy
Absorption Characteristics of New Polymeric Materials" (Confidential)

Speakers: Dr. W. A. Shumcliff, Technical Coordinator
Mr. E. S. Emerson, Physicist

Rutgers University, New Brunswick, N. J.

Contract DA19-129-QM-854 "Development of Rigid High Strength Ceramic
Type Materials and Flexible Configurations Shaped to Minimize Brittle
Tendencies" (Confidential)

Speaker: Dr. E. J. Sackett, Professor, School of Ceramics

Bjorksten Research Labs., Inc., Madison, Wisconsin

Contract DA19-129-QM-909 "Investigation of Ballistic Properties of
Personnel Armor Materials" (Confidential)

Speaker: M. E. A. Meyer, Project Leader

Chemical Corps Main Command, Army Chemical Center, Md., Directorate of
Material Research, Chemical Warfare Laboratories

Cross-Servicing Order No. CSO-58-65R.

Speakers: Mr. J. W. Jamieson, Body Armor Branch, Biophysics Division
Mr. G. M. Stewart, Deputy Chief, Body Armor Branch
Biophysics Division

Battelle Memorial Institute, Columbus, O.

Contract DA19-122-QM-933 "Fabrication of Selected Titanium Alloys
for Personnel Armor Applications" (Confidential)

Speaker: Mr. A. M. Sabroff, Research Metallurgist
Light Metals Division

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PAPERS PRESENTED

The Development of Multiphasic Armor Constructions¹

A. L. Alessi*

The historical background of multiphasic armor was outlined and an explanation of the synergistic effect obtainable with such armor proposed in terms of combinations of missile stopping and missile-retarding effectiveness of the components.

The results of exploratory experiments were presented, demonstrating that composite armor consisting of two or more dissimilar materials is capable of producing substantially greater protection than an equivalent weight per unit area of any one component. Data were shown for three systems of two components each and tested with the 17 grain .22 caliber T37 fragment simulating projectile. Measures of the ability to defeat missiles (such as the V₅₀ ballistic resistance limit) and to retard missiles were presented as guides for the selection and positioning of components within a composite. Data on residual velocity as a function of missile-striking velocity obtained with the 17 grain .22 caliber T37 fragment simulator for five materials (nylon cloth, titanium A-110AT, aluminum 24S-T3, glass and polymethyl methacrylate) were presented. By application of the synergistic effect obtainable with composite armor, significant advances are anticipated in providing protection for personnel, vehicles, shelters and equipment against battlefield threats.

¹Published in more complete form as Quartermaster Research & Engineering Command Technical Report CP-5, Composite Personnel Armor, Dec. 1957 (C).
*Quartermaster Research & Engineering Center, Natick, Massachusetts.

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Energy Absorption of Single Layers and Composite Armor Structures¹

A. S. Tenta*

The work carried out by the Quartermaster Research and Engineering Center ballistic test range on the ballistic energy absorption of personnel armor materials was presented.

Generally, similar relationships were found for both the caliber .22 and .35 fragment simulating projectiles, viz. (a) materials differ markedly in their ability to retard projectiles, (b) the energy loss of penetrating projectiles divided by the areal (surface) density of the material was found to be velocity-dependent for all materials and (c) the relationship between materials changes with projectile striking velocity.

The kinetic energy loss of the caliber .15 projectile was approximately one half that of the caliber .22 projectile. Comparison on the basis of the projectile striking energy, however, shows that the percentage loss is greater for the caliber .15 projectile.

Limited energy absorption studies have been made on a few composite structures utilizing a rigid material in front and nylon armor fabric in back. Some combinations such as glass-nylon and polymethyl methacrylate-nylon were found to reduce the kinetic energy of the projectile (per unit areal density) to a greater extent than either component.

¹Published in part as Quartermaster Research & Engineering Center Report QMRE-14, Investigation of Ballistic Protective Materials for Personnel Armor, Progress Report I, Energy Absorption and Ballistic Resistance Limits (V_{50}) of Armor Materials when Perforated by a Fragment Simulating Missile (.22 caliber T37), December 1957 (Confidential).

*Quartermaster Research & Engineering Center, Natick, Massachusetts

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Report by the Polaroid Corporation¹

W. A. Shurcliff*

Perhaps in 10 or 20 years, science will be sufficiently advanced to permit man to arrive at a detailed understanding of the action of an armor panel in stopping a projectile. Today, we lack the scientific foundation on which to base such an understanding. The subject is further handicapped by lack of any textbook and any technical society devoted to the subject of personnel armor. Also, the secrecy which shrouds the subject hinders stimulating discussions among scientists in different organizations.

Some Ballistic Properties of CR-39 Plates

E. S. Emerson²

Because glass shows such great energy absorption from fast missiles (missiles whose striking speed exceeds the V_{50} value of the panels fired at), we tried to see what organic polymeric material might be enough like glass to exhibit correspondingly high energy absorption but might avoid glass bad features, such as high density and tendency to shatter into sharp-edged pieces. The material known as CR-39 appeared to be a good prospect. Firing tests were made and our expectations were borne out. CR-39 plates that are thicker than $1\frac{1}{4}$ inch show outstanding ability to absorb energy from fast projectiles.

Importance of Type and Extent of Parallelism Among Organic Polymeric Molecules Comprising an Armor Panel

W. A. Shurcliff*

The usual method of describing the orientation (i.e., type and degree of parallelism of the long chain molecules) in polymeric plates that have been strengthened by stretching operations is to describe the stretching procedures used. This method is inadequate: specimens that have been stretched in apparently similar manner may end up with quite different actual type and degree of parallelism among the molecules. A scientifically rigorous method, involving determination of the three principal refractive indices, is recommended.

¹Investigation of the Energy Absorption Characteristics of New Polymeric Materials, Final Report, Dec. 31, 1957, Polaroid Corp., Cambridge, Mass.
*Polaroid Corp., Cambridge, Mass.

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Applicability of Dynamic Photoelastic Analysis to the Study of Impact Phenomena

E. S. Emerson*

An almost ideal method of evaluating the high-speed, dynamic stresses produced in panels of organic polymeric materials by incident missiles is the method known as photoelastic analysis. Curiously enough, the method has been entirely overlooked by persons working in this field. One complication is that some of the formulas commonly used in static photoelastic analysis do not apply. However, several of the principal formulas still do apply, and from these we can derive a detailed account of how the stresses vary from instant to instant and from point to point.

*Polaroid Corp., Cambridge, Mass.

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Properties of Technical Ceramics

Edward J. Sposko*

The first objective of contract DA19-129 GM-854 is to determine the ballistic properties of ceramic materials. Preliminary specimens of three types of crystalline ceramics have been submitted for test, namely alumina, zircon and steatite. They range in areal density from 57 to 117 oz./sq. ft. In the ballistic tests, the striking velocity ranged from 5,265 to 2,200 ft./sec. while the residual velocity ranged from 2,687 to 540 ft./sec. This results in the ceramic lowering the velocity in the range of 47 to 84%. In all cases, the ceramic shattered and splintered in the area of impact. It has been proved that, in some cases, the recorded residual velocity is that of a fragment of ceramic since the missile did not penetrate the ceramic. Specimens are being prepared in lower areal densities for further evaluation.

A general discussion of the engineering properties of ceramic materials was also presented. Information on glass, single crystals, polycrystalline, and crystal glass type ceramics was included. Physical strength of highly porous types of ceramics is quite low, in the range of several hundred pounds per square inch. The maximum value for tensile strength is 27,000 psi, transverse strength, 60,000 psi; and compressive strength, 60,000 psi. Other properties are:

Hardness - 27 to 7,000 (Knoop)

Linear Thermal Expansion - 5.6 to 19×10^{-6} in./in./°C.
(25 to 700°C.)

Thermal Conductivity - 0.05 to 125 Btu/(hr.)(ft.²)(°F.)/ft.

Impact Strength - 3 to 40 in.-lbs./sq. in.

*Professor of Ceramics, School of Ceramics, Rutgers, The State University, New Brunswick, N. J.

Measurement of the Energy Absorption Characteristics
of Materials as a Function of Projectile Velocity¹

E. A. Meyer*

A comparison check was made between the two velocity-measuring systems which are to be used for energy absorption measurements. Serious disagreement was noted only in the velocity interval between 1130 and 1240 ft./sec. The disagreement ranged from 23 to 55 ft./sec., whereas outside this interval they agreed within several ft./sec. Since even slight disagreement in velocity measurement can produce huge errors in the measurement of energy absorption, it was imperative that the cause be understood and corrected. Tests showed that the problem which existed with the T37 projectiles could be adequately simulated with bullets. Since about 10,000 rounds were fired in this investigation, the savings in cost and time were considerable.

High-speed flash photographs of bullets at various velocities were taken at the instant they triggered the lumiline screens. Relative bullet position were obtained by superimposing negatives. The results showed that bullets travelling at different velocities triggered the residual velocity lumiline screen all at the same position. This was also the case for the striking velocity screen at velocities below 1130 ft./sec. At 1130 ft./sec., the bullet position abruptly jumped back 1-1/2 inch (toward gun) at the instant this screen was triggered. As the bullet velocity was increased, this pre-triggering distance decreased until it was only 3/16 in. at 1300 ft./sec. This phenomenon alone could account for the velocity disagreement observed, which also showed an abrupt change at 1130 ft./sec. It is of interest to note that the velocity of sound under our test conditions is about 1140 ft./sec.

Additional tests suggested that the pre-triggering was caused by interaction between the shock wave which precedes the bullet at sound velocities and the light beam. There was no evidence that the pre-triggering was caused by mechanical interaction between the shock wave and the tubes of the lumiline screen (e.g., microphonics).

Tests were conducted which showed that pre-triggering depended on light beam intensity, photomultiplier sensitivity and amplifier gain. If these variables are wisely controlled, they can prevent pulse saturation in the amplifier. This permits optimum use of the output thyatron as an amplitude discriminator to screen out the shock pulses, ordinarily far

¹Published as First Quarterly Report, Contract DA19-123-G4-909, Information Regarding the Energy Absorbing Characteristics of Materials for Utilization in Armor, E. A. Meyer, R. J. Hansen, Bjorksten Research Labs., Madison, Wisc., June 30, 1957.

*Bjorksten Research Labs., Madison, Wisc.

smaller than the bullet pulse, and permit only the bullet pulse to pass. While it was possible to eliminate pre-triggering by this method, it did not allow a sufficient safety factor. It was, therefore, necessary to find some other means of reducing the shock pulse amplitude.

Further investigation revealed there were actually three distinct types of shock pulses preceding the bullet at sound velocities. All are due to the dense, compressed air of the shock wave front acting as a lens and refracting the light beam 0.2° toward the gun. This corresponds to a $1/32$ in. shift in the light beam at the photomultiplier tube. The interface shock pulse and the normal shock pulse are of the same polarity as the bullet pulse and, therefore, could cause pre-triggering error. The inverse shock pulse is of the opposite polarity and therefore harmless.

The interface shock pulse, observed only on the striking velocity lumiline screens, was caused by the light beam being masked by the back side of the lower slit (toward gun) during refraction. This reduced the light striking the photocathode and produced the pulse. It was eliminated by moving the lower slit upward and firing below this slit.

The normal shock pulse can be caused either by a reduction in the light striking the photocathode or by the light beam shift to a less sensitive portion of the photocathode. The light level is reduced during refraction if the back portion of the photocathode is masked. The decrease in sensitivity results when the light beam is positioned on the back portion of the photocathode so that refraction moves it away from the much more sensitive center portion.

The inverse shock pulse can be caused either by an increase in the light striking the photocathode or by the light beam shift to a more sensitive portion of the photocathode. The light level is increased during refraction if the front portion of the photocathode is masked. The increase in sensitivity results when the light beam is positioned on the front portion of the photocathode so that refraction moves it toward the much more sensitive center portion.

The normal shock pulse was eliminated by making certain that the back side of the light beam was not masked and by positioning the beam on the front portion of the photocathode surface. Then, only an inverse shock pulse results which cannot trigger the thyratron and cause pre-triggering error.

The results of this investigation apply specifically to our modified lumiline screens with the 0.024-in. slits. However, normal shock pulses of sufficient amplitude to cause pre-triggering error were observed on the standard, unmodified high velocity lumiline screens.

Chronograph agreement tests were conducted by connecting all four chronographs in parallel to a set of lumiline screens. One of the chronographs was consistently low by 0.02 millisecond. Pickup from the start circuit distorted the oscillator wave form for the first few cycles and these counts were missed.

The interaction was eliminated by shielding the wires which originated in the start circuit and which passed behind the oscillator condensers. The same interaction was noted in the other chronographs but to lesser degrees. Since it represents a potential source of error, they were all shielded. All four chronographs then agreed within 0.01 millisecond.

A final comparison check was made between the two velocity-measuring systems. They agreed within experimental error and no anomaly was observed in the velocity of sound region. The velocity difference between systems ranged from -3 to 8 ft./sec. as compared to -23 to 55 ft./sec. at the start of this investigation. Of the 11 ft./sec. spread observed, 8 ft./sec. can be attributed to the minimum chronograph resolution of ± 4 ft./sec. at these velocities. The remaining 3 ft./sec. variation could easily be due to changes in drag, since both clipped and undeformed bullets were fired. Tests with T37 projectiles also showed agreement within experimental error over the complete velocity range from 360 to 2100 ft./sec.

The important requirement on the proper choice of drag coefficient is that the projectile striking velocity (V_s) and the residual velocity (V_r) agree closely at the target plane in the absence of a target. Any appreciable difference can introduce serious error on energy absorption measurements. Using this condition, the drag coefficient for T37 projectiles was determined experimentally over the velocity range from 100 to 2200 ft./sec.

The values of the drag coefficient determined by Aberdeen Proving Ground and Watertown Arsenal were compared with that measured at our laboratory. Comparison was made of the computed values of ($V_s - V_r$) without a target using the three different values of drag coefficient on 21 rounds covering the velocity range. The least error was obtained using the Bjorksten drag coefficient.

Energy absorption measurements were started on both plastic and metallic target materials. High-speed flash photographs showed that the residual velocity screens were pre-triggered by target fragments from both targets. Correction must therefore be made for the pre-triggering, to avoid serious error in energy absorption measurements. This correction can be obtained from the projectile-to-slit distance measured from a photograph taken at the instant each residual velocity screen is triggered.

The energy absorption efficiency of 1/32 in. Micarta 259-2 for T37 projectiles at various striking velocities was presented. Correction for pre-triggering by target fragments was made by the photographic technique for each round fired.

Technique for Determining Strain History of Yarns under High Speed Impact

J. W. Jamason*

To assist in the study of energy absorption in armor materials, an apparatus has been developed for obtaining on a single photograph the complete history of the strain distribution in a single yarn impacted by a projectile. The camera, set for time exposure, sees the object in a rotating mirror, and several pictures of the yarn in successive states of deformation are made by flashes of light, each of microsecond duration. Data can now be obtained directly to describe the strain at a point on the impacted yarn as a function of time. The method can also be applied to other subjects.

A New Technique for Determining Transient Deformation

G. M. Stewart*

A new photographic technique for determining the amount of transient deformation of a material at a known time after impact is now in use at Biophysics Division, Army Chemical Center, Md. This technique involves the use of a multiple microflash unit, type 2518, developed for Biophysics Division by Edgerton, Germeshausen and Grier, Inc. The unit consists of a power supply, a triggering pulser, and 20 flash units which are set off in rapid sequence. The light source is a single flash tube, with a reflector assembly and each of the 20 flashes is of approximately one microsecond duration. The interval between flashes may be set at 10, 20, 40, 80 or 160 microseconds.

During a test, a photograph is taken of the impacted target. From this negative, one can determine by measurement the maximum transient deformation. This is done as follows: the distance from the back of the target to the farthest displaced image is measured on the negative. The number of flashes that occurred before impact is known and the number of flashes after impact is determined by counting the images of the displaced portion. If the total is less than 20, it can be assumed that the missing flashes occurred after the maximum transient deformation was reached.

Using the above techniques, it is possible to determine with accuracy the maximum transient deformation for impacted targets such as helmets, fabrics, metals, tissue and protective lenses.

*Chemical Corps Research & Development Command, Army Chemical Center, Md.

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Development of Titanium Alloys under Quartermaster Contract

A. M. Sabroff*

The desirable combination of high strength and low density which titanium and its alloys possess has interested a number of agencies in the possibility of using these materials in armor application. Ballistic studies conducted by Watertown Arsenal, Bureau of Aeronautics and Naval Proving Ground as far back as 1951 have shown that certain titanium alloys exhibit ballistic performance against fragments and armor-piercing projectiles equal to or better than that of many of the metallic armor materials now in use. In research on titanium alloys for aircraft armor applications conducted by Battelle for the Bureau of Aeronautics, for example, an alloy having the nominal composition Ti-3Mn-1Cr-1Fe-1Mo-IV, when properly fabricated and heat-treated, showed better resistance to fragment simulators than the presently used aluminum alloys on an equivalent weight basis.

Most of the armor programs on titanium, however, have been concerned with applications requiring areal densities in the range 2.5 to 7.5 lb./sq. ft. Comparatively little work has been done on titanium alloys in sheet sizes of interest for personnel armor, namely, those with areal densities below 2.5 lb./sq. ft. Recent studies at the Quartermaster Research & Engineering Center on various titanium alloys, however, have shown highly promising results.

The objective of the Quartermaster Corps program at Battelle is to establish the conditions under which the most promising alloys developed thus far must be processed for personnel armor applications. Although considerable data are available on heavier gages, ballistic performance cannot be extrapolated to lighter gages because of difference in various metallurgical characteristics, for example (1) grain size, (2) tolerances for impurities and (3) notch sensitivity. This is probably true from the mechanical standpoint as well, considering only the differences in geometry.

Initially, six alloys exhibiting alpha, alpha-beta or beta microstructures will be studied:

Ti-3Mn-1Cr-1Fe-1Mo-IV
Ti-3Mn-1Cr-1Fe-1Mo-IV-4Al
Ti-6Al-4V
Ti-5Al-2.5Sn
Ti-16V-2.5Al
Ti-6Al-3Mo

*Battelle Memorial Institute, Columbus, O.

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Except for the α -Ti-5Al-2.5Sn alloy, which is not heat-treatable, the alloys will be tested in the following conditions:

- (1) Fully annealed.
- (2) Heat treated to about 20,000 to 25,000 psi higher in ultimate tensile strength than the annealed condition.
- (3) Heat treated to about 40,000 to 50,000 psi higher in ultimate tensile strength than the annealed condition.

In addition, the Ti-6Al-4V alloy and possibly one other alloy will be heat-treated to produce a range of yield strength/ultimate strength ratios. This material will be used to study the effect of the spread between yield and ultimate strengths on ballistic performance.

The alloys will be studied in two sizes covering an areal density range of 1 to 2.5 lb./sq. ft. The materials will be evaluated in the G-2 ballistic test for both V_{50} and energy absorption characteristics. The most promising alloys will be studied over a wider range of conditions in an attempt to establish the optimum condition for armor applications.

On completion of the studies outlined, the most promising alloys will be studied in a wide range of sheet sizes covering a range of areal densities from about 0.5 to 2.5 lb./sq. ft., to obtain data for use in developing not only titanium armors, but also composites of titanium with other materials.

RECOMMENDATIONS

Many of the participants and those in attendance volunteered highly favorable comments on the worth of the armor materials symposium in contributing to their knowledge and in stimulating ideas. On the basis of these comments, the following recommendations are made:

1. For each broad area of a project wherein there are many groups, Command contractors, division laboratories or others involved, annual meetings of all interested groups be held to promote communication between the working groups.
2. The meetings be conducted on an informal basis with ample time allowed for discussion.

ACKNOWLEDGEMENTS

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