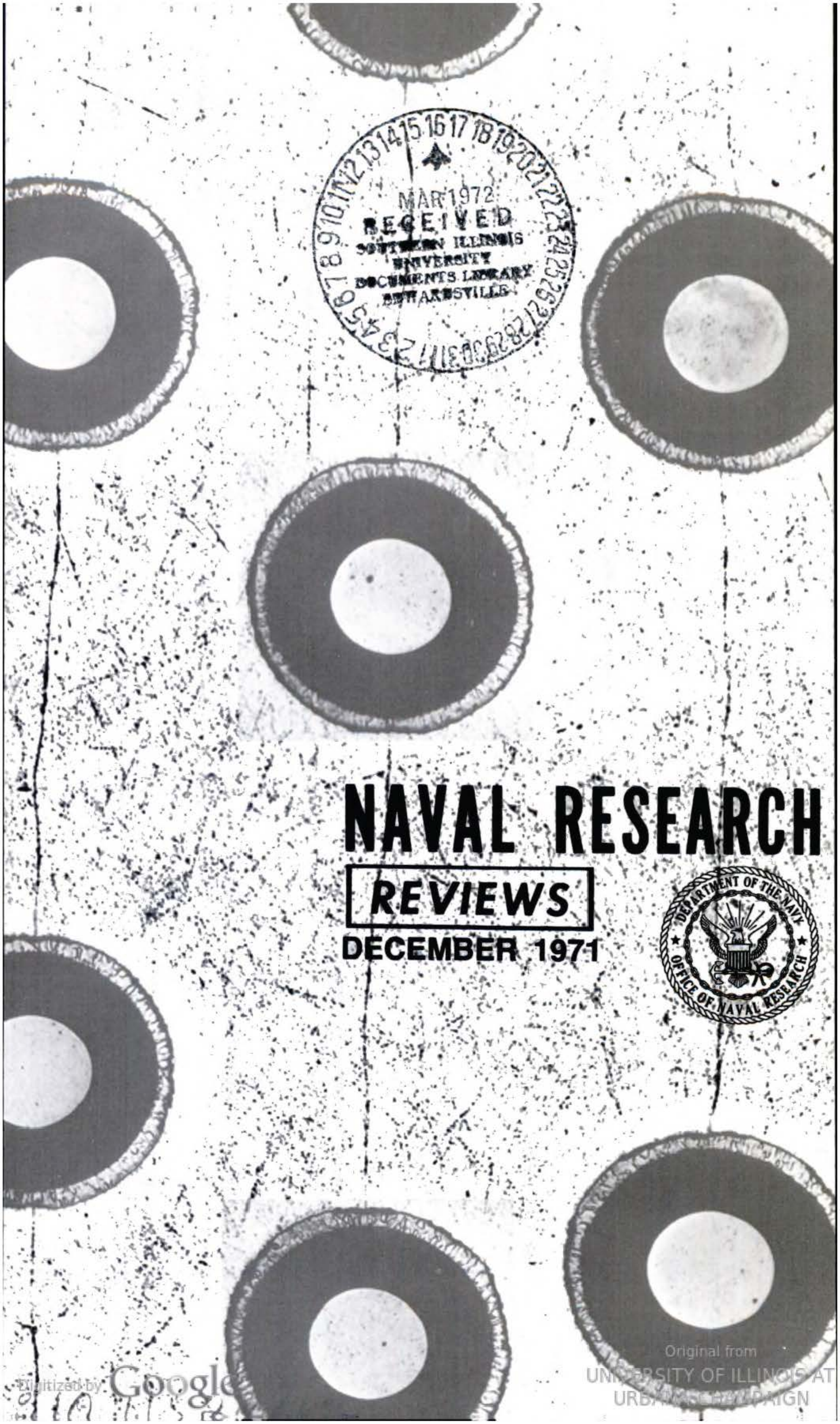


NAVAL RESEARCH REVIEWS

DECEMBER 1971

Conrad Award

On January 6, 1972, the Honorable Robert A. Frosch, Assistant Secretary of the Navy for Research and Development presented the Conrad Award to Dr. Harry Hoogstraal, head of the Medical Zoology Department of the U.S. Naval Medical Research Unit No. 3 (NAMRU-3). The Unit, located in Cairo, UAR, is a research facility of the Navy's Bureau of Medicine and Surgery concerned with investigations on infectious diseases endemic to the Middle East and Africa.

The Conrad Award, the highest Navy award for scientific achievement, is given annually to an individual who has made an outstanding contribution in the field of research and development for the Department of the Navy. It was established in 1957 by the Secretary of the Navy in honor of Navy Captain Robert D. Conrad who was the first Director of Research for the Office of Naval Research and one of the primary architects of the Navy's basic research program. Dr. Hoogstraal was given the award in recognition of his contributions to naval medical research in the field of insect-borne diseases, especially tick-borne diseases. Dr. Hoogstraal established the Medical Zoology Department of NAMRU-3 in 1950 and has served as head ever since. During his more than 20 years of work there, he established a reputation as the foremost authority in the world on ticks and tick-borne diseases. Some of his most recent accomplishments are listed below:

1. *Epidemiologic pattern and transmission factors of kala azar in the Sudan.* This study has delineated the epidemiology of kala azar in the Sudan in such a fashion that previous empirical observations are now explained in terms on known cause and effect. Similarly, the bases for certain transmission factors have been explained by careful studies of vector anatomy and behavior.

2. *Studies of the role migratory birds play in disease transmission.* Birds migrating between the continents of Europe, Asia and Africa have been studied in conjunction with the Smithsonian Institution. These birds and their ectoparasites have been found to carry several serious viral and protozoal agents that are known to cause disease in Europe and Asia, but generally have not been detected in Africa. As a result of this study, governments of the United States and African nations have been alerted that these disease agents are in Africa. This information will assist both governments and international health and agriculture organizations with detection of economically important human and animal diseases in developing nations where little or nothing is known of the actual etiology for much human suffering and animal wastage.

3. *Isolation and identification of "new" arthopod-borne viruses.* Several previously unknown tick-borne viruses have been isolated and identified as "new." These have quickly shown to have widespread distribution around the world. Several have been incriminated in serious previously known but unexplained diseases.

(Continued on Inside Back Cover)

Deformation of Metal-Matrix Composites

A. Lawley and R. W. Heckel
Drexel University
Philadelphia, Pa.

Composite materials are attracting attention for future use in many Navy components, ranging from aircraft and submarine structural elements to fan blading in gas turbine engines. Composites are composed of a number of hard particles, aligned filaments, or aligned platelets that are held together in a continuous binder phase. The physical properties of such composites depend on the properties of the reinforcing phase and the binder phase, and it is in the selection of these phases that desirable, unique physical properties can be built into the composities.

The use of composites in structures has been restricted by the high cost of the reinforcing phase, difficulties associated with fabricating and joining composites into desired shapes, and a lack of knowledge on how processing variables affect ultimate physical properties. This last problem area—the interaction of processing techniques on mechanical properties of composites—has been the subject of a research program in the Office of Naval Research for several years. The program has emphasized research on ways to control and characterize structures of the reinforcing phase, binder, and their mutual interfaces so that processing variables can be related to the important mechanical properties including yield strength, creep strength, fatigue strength, and fracture behavior.

This is a second article on ONR-sponsored work in composites' research and centers on the program at Drexel University. The first appeared in the May 1970 issue of Naval Research Reviews *and summarized research on filamentary and particulate composites at Stanford University. This article centers on important features of composite materials related to their processing and ultimate use. The subjects discussed are the prediction of mechanical properties of composites from a knowledge of the properties of the component phases, the proper control of processing variables to build in beneficial residual stresses, and the development of composites that possess good thermal stability and mechanical strength at elevated temperatures.*

Bruce MacDonald
Office of Naval Research

Composite materials consisting of a binder or matrix and a reinforcing phase offer unique combinations of properties. Moreover, the properties of composites can frequently be tailored through careful selection of the constituents, the relative proportions of each, and the method(s) of fabrication. A broad spectrum of combinations is available; in general a composite is based on either a metal or polymer matrix reinforced by a metal or non-metal in the form of whiskers, fibers, filaments, or wires. While much of the research and development in composite materials is centered on mechanical behavior, it is now recognized that electrical or magnetic properties may be tailored through the control of composite structure. This reflects the initial interest and impetus in the development of composite materials on the part of the metallurgical or materials engineer, and a more recent appreciation of the scope and potential of composites by the solid state physicist and electrical engineer.

In the light of current and anticipated materials' requirements of the Navy, metal-matrix composites are of particular interest. Unique combinations of strength to density, stiffness to density, coupled with ductility, toughness, and, frequently, oxidation resistance, provide a compatibility with several areas of application including: materials of structural and dimensional stability; marine and land gas turbine technology; advanced engine design; and airframe structures. Metal-matrix composites are being evaluated, in this context, in terms of cost, fabricability, property variability, and stability.

A first approach to the evaluation of composite materials takes the form of a compilation of mechanical property data as a function of fabrication and processing history, and usually simulated service conditions. Alternatively, the deformation characteristics may be described in terms of micromechanical models of deformation based on the concepts of continuum mechanics. While such studies are necessary, a concurrent appraisal of the microstructural aspects of the deformation mode(s) is vital in the design and development of new and improved composite materials, and in the exploitation of the potential of these materials.

The thrust of broad-based Navy (ONR) programs at Drexel University is to quantitatively evaluate the performance and deformation behavior of selected metal-matrix composites, giving full cognizance to the role of structure. In particular, attention is centered on the role of the interface, the effect of residual stress, and thermal degradation. A detailed knowledge of the nature (structure) and stability of the interface is critical to composite materials technology since this constitutes the direct link in the composite through which shear stresses are transferred from matrix to reinforcement. Residual stresses in the matrix and the reinforcing phase control the extent of totally elastic behavior and therefore provide capabilities for unique structural designs. In this article, a comprehensive and largely qualitative description is given of these aspects of the overall program. The intent is to delineate the importance of the interface, residual stresses, and thermal degradation, and to illustrate the utility of the on-going studies in providing a complete characterization of the composites under stress.

The Rule of Mixtures

In describing the mechanical behavior of continuous fiber-reinforced composites, recourse is often made to the "rule of mixtures." Specific properties of the composite (*e.g.* tensile strength) may be calculated in terms of the stresses on the fiber and matrix, weighted by the volume fraction of each in the composite. Elastic modulus and tensile strength have been documented for a broad spectrum of composite materials, and the experimental data lend support to the applicability of the rule of mixtures.

In its simplest form, the rule of mixtures does not take account of residual stress, Poisson's ratio differences between matrix and reinforcement, fiber diameter, fiber geometry, or fiber spacing. Further, a direct transfer of shear stress across the matrix-fiber interface is implied. Cognizance of these restrictions and conditions leads to a number of important and interesting predictions in terms of the microstructural aspects of the deformation of composite materials. Thus, conformity to rule-of-mixtures behavior has these requirements:

- Independent response to stress on the part of the matrix and reinforcing phase respectively, as though each were the only phase present
- For a given composite strain, the matrix substructure (dislocation density and configurations) should be independent of volume fraction of reinforcement, *i.e.*, identical to the substructure in unreinforced aluminum at an equal level of strain
- For a given level of strain and volume fraction of reinforcement, the matrix substructure should not vary with distance from the matrix-fiber interface (*i.e.* no significant matrix-fiber interface interaction).

These criteria provide an exacting test of the rule of mixtures, and at the same time allow for a detailed examination of the role of the interface on deformation behavior.

Diffusion Bonded Composites

The response of a diffusion bonded (vacuum hot-pressed) continuous fiber metal-matrix composite is illustrated by reference to aluminum reinforced by cold-drawn 0.006″ diameter stainless steel wire (Figure 1). Under *tensile* load parallel to the direction of reinforcement, the precision elastic limit, microyield stress (at a strain 2.5×10^{-6}), and macroyield stress (at a strain 1×10^{-3}) are in close agreement with rule-of-mixtures calculations. Data for the macroyield stress are presented in Figure 2.

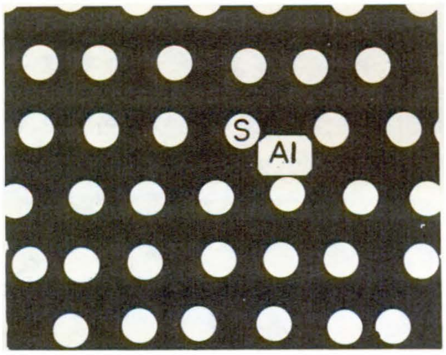


Figure 1 — Cross section of a 0.2 volume fraction aluminum-stainless steel composite. Al = aluminum matrix; S = stainless steel. x43.

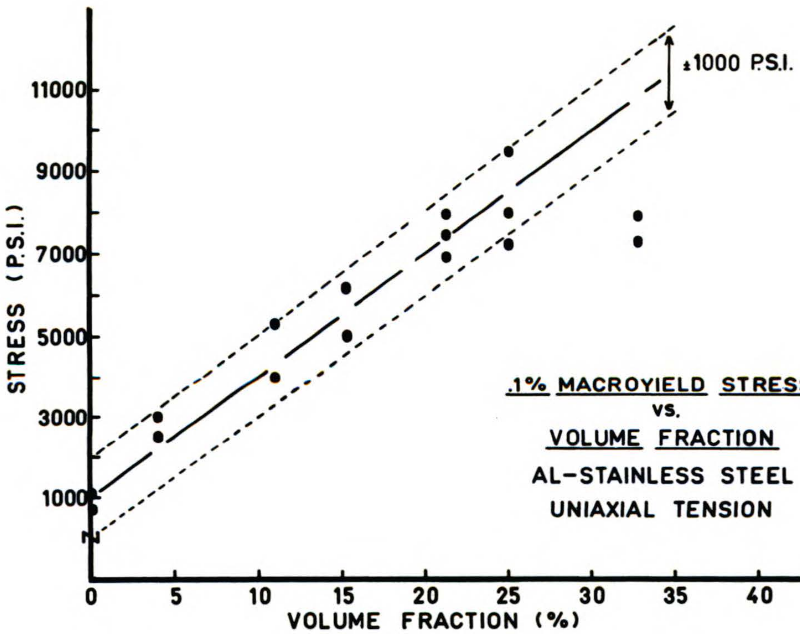
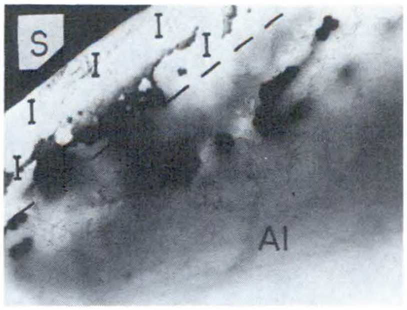
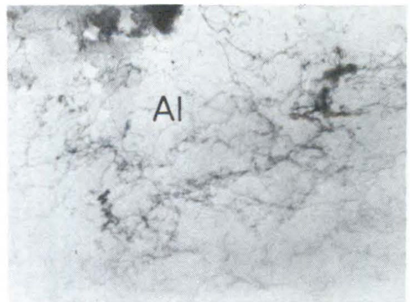


Figure 2 — Macroyield stress (strain 10^{-3}) as a function of volume fraction reinforcement in tension for aluminum-stainless steel. Solid line is 'rule-of-mixtures' calculation. Met. Trans., *1970, Vol. 1, p. 1337 "Correlation of Uniaxial Yielding and Substructure in Aluminum-Stainless Steel Composites," M. R. Pinnel and A. Lawley.*

A detailed and thorough examination of the aluminum matrix substructure by transmission electron microscopy after deformation provides an alternate verification of the applicability of the rule-of-mixtures. In particular, the matrix substructure is independent of distance from the interface at a fixed level of strain and volume fraction of reinforcement (Figure 3); also, at a fixed level of strain in the composite, the matrix substructure is independent of volume fraction of reinforcement and is comparable to the structure of unreinforced aluminum at an equal level of strain.



(a)



(b)

Figure 3 — Aluminum-stainless steel (0.15 volume fraction) strained ~6×10^{-3} showing matrix substructure. (a) at interface, x6500; (b) 40μ from interface, x8000. I = interface; Al = aluminum matrix; SS = stainless steel. (Met. Trans., *1970, Vol. 1, p. 1337 "Correlation of Uniaxial Yielding and Substructure in Aluminum-Stainless Steel Composites," M. R. Pinnel and A. Lawley.)*

Directionally Solidified Eutectic Composites

In directionally solidified eutectics, the interface consists of a precise low-energy crystallographic boundary between the two eutectic constituents. To provide a comparison with aluminum-stainless steel, the *compressive* behavior of lamellar Al-$CuAl_2$ has been correlated with deformation structure at the interface and in the aluminum-rich phase.

The eutectic composites examined in this program, Figure 4, had a small interlamellar spacing $\leqslant 2\mu$ and were found to possess thermally-induced residual stresses: residual tension in the aluminum-rich matrix and compression in the $CuAl_2$ intermetallic. Allowing for the effect of residual stresses in the rule-of-mixtures equation, the actual *in-situ* yield stress of the aluminum-rich phase is significantly higher (13,500 psi compared to ~5500 psi) than that expected. This 'anomaly' is attributed to constraints imposed by the small lamellar spacing. In fact, clear evidence for these constraints is found in the form of dislocation-interface interactions and in a higher dislocation density in the immediate vicinity of the interface compared to central regions of the aluminum-rich lamellae (Figure 5).

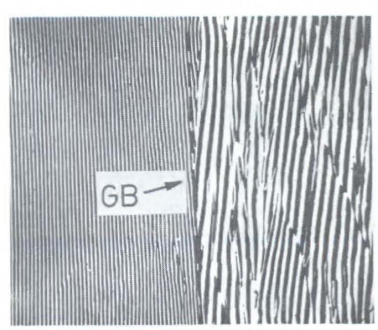
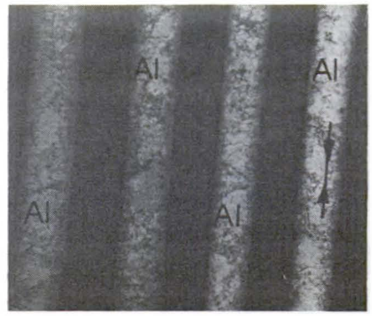


Figure 4 — Longitudinal section of directionally solidified Al-$CuAl_2$ lamellar composite. Note the grain boundary GB. x125. (Met. Trans., *1971, Vol. 2, p. 1529, "Deformation and Fracture in Al-$CuAl_2$ Eutectic Composites," A. Pattnaik and A. Lawley.)*

Figure 5 — Longitudinal section of deformed Al-$CuAl_2$ lamellar composite showing substructure in the aluminum-rich phase; arrows show direction of compression. x8700. (Met. Trans., *1971, Vol. 2, p. 1529, "Deformation and Fracture in Al-$CuAl_2$ Eutectic Composites," A. Pattnaik and A. Lawley.)*



Effect of Mode of Loading

Because of the anisotropic nature of composite materials, and from a consideration of the mechanism of stress transfer from matrix to reinforcement, it is expected that the loading response of composites will be a function of stress-state. This is clearly demonstrated by comparing the behavior of aluminum-stainless steel in simple uniaxial tension and compression. It is recalled that in *tension* the precision elastic limit, microyield stress, and macroyield stress are in close agreement with rule-of-mixtures calculations. However, in *compression* observed stress levels are higher than those calculated from the rule-of-mixtures. For example, the experimental macroyield stress exceeds the calculated stress by almost one order of magnitude. Analysis of the compressive stress-stain curves shows that the stainless steel wires carry most of the load, higher stresses are required than loading in tension to produce a given level of strain in the composite, and the rule-of-mixtures does not apply.

As a further illustration of the effect of mode of loading, constant load tensile creep of aluminum-stainless steel may be described in terms of an exponential form of a rule-of-mixtures equation which relates composite creep rate to applied stress and volume fraction of reinforcement of aluminum with stainless steel wires does significantly reduce the tensile creep rate at a given level of stress. In comformity with these creep measurements, the matrix substructure is found to be independent of distance from the matrix-wire interface for a given creep strain and volume fraction reinforcement. Again this confirms a simple mechanical shear stress transfer across the interfaces in the composite.

Residual Stress Effects in Composites

Residual Stresses and Yielding

One of the more recently uncovered effects on the mechanical properties of composite materials is due to the presence of residual stresses. In order to simplify the discussion of this effect, we can assume that such stresses, when present in a composite prior to the application of a service load, are parallel to the direction of the fibers. Balance of force requirements within the composite prior to loading dictate that tensile stresses in the fibers must be balanced by compressive stresses in the matrix, or vice versa.

Residual stresses are most noticeable in their effect on the initial yield point of the composite (end of stage I deformation). In most composite systems, this yield point corresponds to the onset of plastic deformation of the matrix, since it occurs at stresses which are considerably less than those necessary to cause yielding or fracture of the fibers. If the residual stress in the matrix is tensile, the composite exhibits a lower yield strength in tension since the matrix can be considered to be partially along the path to yielding prior to the initiation of loading. Compressive residual stresses in the matrix, on the other hand, raise the yield strength of the composite for tensile loads. Thus, compressive residual stresses in the matrix (tensile in the fibers) give improved elastic behavior of composites for tensile loads. Conversely, improved elastic compression behavior of composites will result from tensile residual stresses in the matrix (compressive in the fibers).

Residual stresses have been shown to exist in composites fabricated by either directional solidification of eutectics or hot pressing of layers of wires and metal foils. The residual stresses in as-fabricated composites usually arise from differences in the coefficient of thermal expansion between the matrix and fibers. Thermally induced residual stresses generally result in tensile residual stresses in the matrix (improved compression behavior, but poor tension behavior) since the coefficient of expansion of the fibers is less than that of the matrix. Thus, on cooling from the elevated temperatures used for fabrication, the matrix will try to contract more than the fibers, but due to the bonding to the fibers, the matrix will be restricted in the amount of contraction permitted. The net result is that, after cooling to room temperature, the matrix remains in a state of residual tensile stress which is balanced by residual compressive stress in the fibers. As mentioned previously, this state of residual stress gives a low stage I composite yield stress upon application of a tensile load, since the matrix is in effect prestressed prior to loading.

Thermally-Induced Residual Stress

The presence and effects of these thermally induced residual stresses have been studied in the present research program by comparing the tensile and compressive stage I yield stresses in directionally solidified eutectics in the Al-Cu alloy system. The yield stresses measured in compression were always larger in magnitude than those measured in tension. The tensile residual stresses in the matrix due to different thermal expansion coefficients of the Al (matrix) and $CuAl_2$ phases present in these composites resulted in premature yielding in tension and higher than expected compressive yield strengths. Thus, residual stresses due to differential thermal expansion effects are favorable for compression loading and unfavorable for tensile loading.

Deformation-Induced Residual Stress

It has been shown that mechanical deformation may also be used to develop residual stresses. If a composite is prestrained in tension past the yield point of the matrix (into the stage II deformation range), the composite upon unloading will have a different state of residual stress than that prior to loading. Consider the typical example of a composite with high modulus fibers in a low-modulus matrix which has been prestrained past the stage I yield point. Although the stress in the fibers increases linearly with strain in the stage II region (fibers deforming elastically), the matrix stress increases only slightly with strain (work hardening only) since plastic deformation is occurring. Thus, on unloading from this prestrain, the fibers contract and drive the matrix into compression because of the bonding across the fiber-matrix interface. The result of the tensile prestraining into the stage II deformation region is, therefore, a state of compressive residual stress in the matrix counterbalanced by a tensile residual stress in the fibers (the opposite situation to that resulting from differential thermal expansion effects). It may be seen that tensile prestraining treatments provide composites suitable for tensile loading conditions (*i.e.*, large stage I tensile yield stresses) just as differential thermal expansion effects give rise to improved compression loading performance.

The effects of tensile prestraining were demonstrated experimentally in the present research program on composites fabricated by pressure bonding alternate layers of 2024 Al foils and aligned 0.005 in. diameter W wires at elevated temperatures. A series of composites ranging from 8 to 40 volume percent W wires was studied using a prestrain of 4.2×10^{-3} in./in. which was sufficient to cause deformation into the stage II region. An as-fabricated (not prestrained) composite was tension tested for each volume fraction studied in order to provide a standard of comparison for the tests on the prestrained composites. The experiments showed that tensile prestraining improved the stage I tensile yield strength by better than a factor of two in all instances and, for one composite, by a factor of seven. The tension test data for this study are given in Figure 6 for the entire range of W volume fractions studied; the stress-strain curves for the prestrained composites are marked "P" and the open circles indicate the stage I yield strength for each test. Figure 6 also shows the optimum stage I yield strengths (closed circles) based upon a theoretical deformation model defined in terms of ideal elastic-plastic behavior of both the fibers and matrix. It may be seen that the experimental values closely approach the theoretically predicted values.

This prestraining technique is applicable to the wide range of composite materials containing matrices capable of plastic deformation on prestraining. Normally, if the as-fabricated condition is free of residual stresses, a factor-of-two improvement in the stage I yield strength is to be expected. For situations where thermally induced residual stresses (tensile in the matrix) are present in the as-fabricated composites, as was the situation for the data in Figure 6, the improvement in stage I yield strength can greatly exceed the anticipated factor-of-two.

Prestraining treatments for many existing composite systems provide a significant means for improving the performance characteristics of these materials for situations were a maximum range of elastic response is required. Some of the more obvious applications include:

a. *Improved tensile yield strength for composites currently available.* Tensile prestraining will provide at least a factor-of-two increase in load capability while maintaining totally elastic material response.
b. *Decreased amount of fiber necessary to achieve the same stage I yield strength.* For many composite systems, the major material cost is dictated primarily by fiber cost. Prestraining may be used to offset some of the effect of reduced fiber content if stage I yield strength is the primary design criterion (see data in Figure 6).

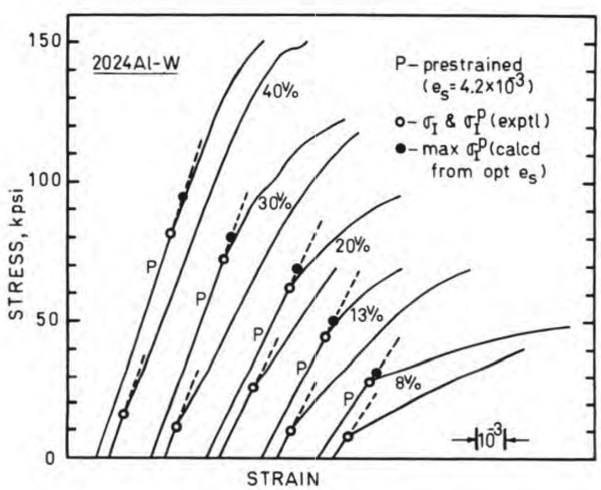


Figure 6 — Stress-strain curves for 2024 Al (matrix)-W(fiber) composites having volume fractions of W between 8 and 40 percent. Curves marked "P" have been prestrained 4.2×10^{-3} in./in. Stage I yield strengths are marked with open circles. Theoretically predicted Stage I yield strengths for prestrained composites are indicated by closed circles.

c. *Reduction in stage I yield strength variations in as-fabricated composites due to variations in processing conditions.* Prestraining not only can be used to increase the stage I yield strength, but also provides a means for removing the residual stresses from as-fabricated composites.

d. *Capabilities for unique structural designs.* The flexibility in achieving a wide range of residual stress states (either by differential thermal expansion effects or tensile prestraining) provides many possibilities for unique structural designs. For example, highly elastic I-beams for use under bending conditions can be constructed with as-fabricated composites (residual tension in the matrix) on the compression side of the beam and tension prestrained composites (residual compression in the matrix) on the tensile side of the beam. Such a design would allow markedly increased bending loads while still maintaining elastic stress-strain behavior in the beam.

Thermal Degradation of Composites

Origin of Degradation

Composite materials are generally fabricated at elevated temperatures and are, therefore, often subjected to thermal degradation effects. Additionally, projected uses of composites include high-temperature environments which may cause further degradation. Although some forms of thermal degradation can occur in composites fabricated by unidirectional solidification, the most extreme forms of degradation are found in composites fabricated by hot pressing alternate layers of metal foils and wires. Thermal degradation in these systems is usually associated with the solid-state interdiffusion of the atomic species in the filaments with those in the matrix. In effect, the interdiffusion process associated with each wire may be considered as a diffusion couple of cylindrical geometry.

It is to be expected, therefore, that the various phenomena observed in ordinary planar-geometry diffusion couples should be found in the thermal degradation of hot-pressed composites. In particular, the formation of intermediate phases and porosity (due to the Kirkendall effect) should be evident in some systems, as well as normal interdiffusions of the atomic species. In extreme situations, where the wires are highly soluble in the matrix, the volume fraction of the fiber phase should decrease during the thermal degradation process.

Degradation of Wire-Reinforced Composites

The thermal stability of composites of ferritic stainless steel wires (15.5 percent Cr, 4.3 percent Ni, 2.7 percent Mo) in a pure Al matrix were studied in the present research program. Tension tests were carried out on composites containing 19.6 percent wires in the as-fabricated condition and after elevated-temperature exposures at 550 and 625°C for 24 hours. The extent of degradation at elevated temperatures was indicated by the marked decrease in yield strength (both stage I and stage II yield points), tensile strength, and elongation at fracture. These data are presented in Table 1. The degradation of mechanical properties in this composite system is due primarily to the formation of a layer of brittle intermetallic phase at the wire-matrix interface. On tensile loading, cracks form in this layer and subsequently propagate transversely through the composite. The formation of cracks occurs at very small amounts of deformation, as shown in Figure 7. Scanning electron microscopy of the actual fracture surface provides further evidence of the reduced ductility of the composite due to thermal degradation (Figure 8). The extensive necking of the wire reinforcement in the as-pressed composite (Figure 8(a)), contrasts with the reduced ductility of the wire reinforcement after heat-treatment at 550°C (Figure 8(b)); thermal degradation has led to the formation of a "corn-cob" structure on the wire surface at the interfaces.

Coatings

One solution to the thermal stability problem has been the use of coatings on the fibers in order to form a barrier to the reaction between

TABLE 1
Tension Test Data on Al-Stainless Steel Composites (19.6% Stainless Steel Wires) in the As-Fabricated (Hot-Pressed) and Thermally Degraded Conditions

Condition	Yield Stress, psi		Tensile Strength, psi	Elongation at Fracture, %
	Stage I	Stage II		
As-Fabricated	11,000	55,000	88,000	2.1
Thermally Degraded (550°C-24 hr.)	10,000	33,000	69,000	2.1
Thermally Degraded (625°C-24 hr.)	7,500	18,000	34,000	1.3

the matrix and the fibers. Since degradation is often an interdiffusion problem, the coatings are chosen to minimize the solid-state transport of atomic species from fiber to matrix and vice versa. In addition, coatings may also be selected on the basis of promoting the bonding between the fibers and the matrix which is essential for optimum composite performance. If minimization of diffusional interaction is of primary importance, the principles underlying coating selection are fairly well defined. To a first approximation, the rate of transport through the coating is proportional to the product of the range of solubility of the diffusing atomic species in the coating and the diffusion coefficient of that species, both of which are markedly sensitive to temperature and coating material. In addition, the rate of transport is inversely proportional to the coating thickness. Ordinarily, coatings are designed on the basis of minimum solubility and diffusion coefficient because of the wide range of material behavior embodied in these terms; reducing the rate of interdiffusion by increasing the coating thickness is often uneconomical and in the limit can greatly alter the mechanical behavior of the composite due to the addition of the third component to the system. Thin coatings of high

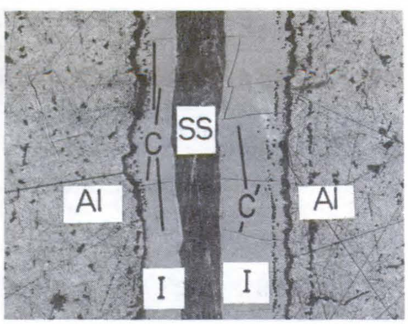


Figure 7 — Cracks present in the intermediate phase in thermally degraded aluminum-stainless steel. SS = stainless steel; Al = aluminum matrix; I = intermediate phase; C = cracks.

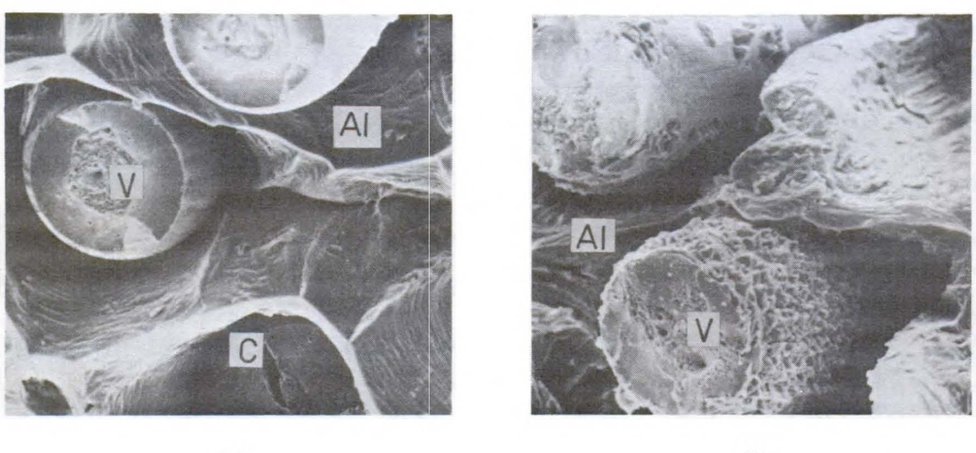


Figure 8 — Scanning electron micrographs of aluminum-stainless steel fracture surfaces (0.2 volume fraction). (a) as-pressed, x300; (b) heat-heated 24 hours at 550°C, x340. Al = matrix; V = voids; C = cracks.

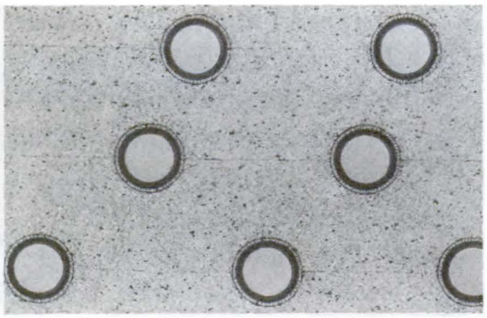
melting metals and refractory compounds appear at the present time to offer the greatest potential for most composite systems. It should be noted that even though coatings may be designed to retard thermal degradation by minimizing interdiffusion, coatings may not be assumed to eliminate the problem entirely.

Stable Composite Structures

An alternate approach to improved thermal stability has been considered in the present research program. The interdiffusion processes described previously for hot pressed composites occur because of the concentration gradients present in the as-fabricated condition. The diffusional degradation which is observed represents a process whereby not only the structure of the composite is altered, but also the gradients are removed. In the limit, the composite structure will equilibrate to a new structure (free of gradients) which can often be predicted by simple phase equilibrium considerations. Thus, the structure of the as-fabricated composite can be designed such that, after thermal equilibration (complete degradation), the desired structure is obtained.

This new concept, growth of composites by solid-state interdiffusion, was demonstrated experimentally to give structures after equilibration similar in geometry to those fabricated by hot pressing alternate layers of wires and foils. The demonstration of the technique was carried out on the aluminum-nickel alloy system because of the understanding of the interdiffusion processes in this system developed by other workers. It was desired to obtain a composite of Al_3Ni fibers in a matrix of aluminum. To achieve this structure, alternate layers of nickel wires (7 percent by volume) and aluminum foils were pressure bonded at 500°C (450 psi) for 3.5 hr. This treatment gave a fully-dense composite and initiated the interdiffusion reaction process. Figure 9(a) shows that rims of both Al_3Ni (grey) and Al_3Ni_2 (black) formed at the interface between the nickel wires and aluminum matrix during this treatment. Further reaction was achieved by a treatment at 600°C for 2.5 hr.; Figure 9(b) shows the growth of the Al_3Ni and Al_3Ni_2 rims and the decrease in size of the nickel-rich phase. Essentially complete reaction of the composite (equilibration) was achieved with a treatment of 70 hr. at 600°C as shown in Figure 9(c), where the desired endpoint structure of Al_3Ni fibers in equilibrium with an aluminum matrix has been achieved. The final volume fraction of Al_3Ni fibers is 37 percent; this value is in agreement with predictions based on phase equilibrium considerations.

Mechanical property testing of diffusion-grown Al_3Ni-aluminum composites indicated that elastic modulus values were satisfactory and in agreement with theory. However, the strengths of these composites were quite low, primarily due to the low strength of the Al_3Ni fibers (some cracks may be observed in the Al_3Ni in Figure 9(c)). The photomicrographs in Figure 9 do indicate that diffusional growth of composite-type structures is possible; other alloy systems may provide a better evaluation of the potential of this fabrication technique for composites with improved mechanical behavior. This technique may also be of use in the fabrication of composites having tailored physical properties, such as electrical conductivity and magnetic behavior.



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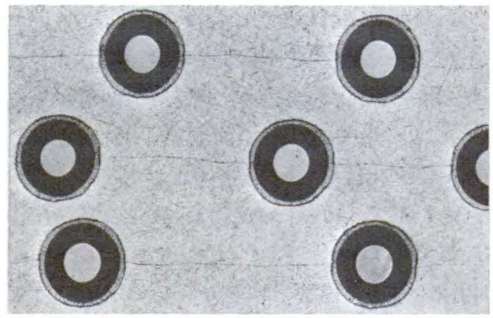

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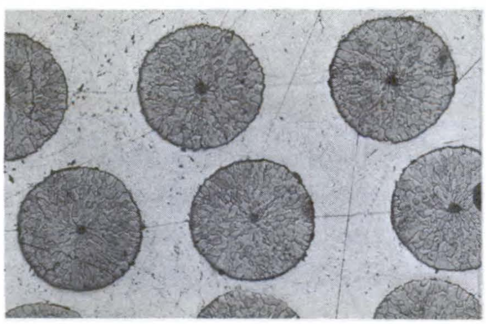

(c)

Figure 9 — Growth of Al_3Ni (fiber)-aluminum (matrix) composites by interdiffusion in an initial structure formed by hot pressing alternate layers of nickel wires and aluminum foils. (a) as-hot-pressed (500°C, 450 psi, 3.5 hr.). (b) hot pressed plus 600°C for 2.5 hr. (c) hot pressed plus 600°C for 70 hr. x100. (Met. Trans., *1971, Vol. 2, p. 325 "Fabrication of Composites by Diffusion Processing," T. Darroudi, K. M. Vedula, R. W. Heckel.)*

Summary

Distinct and diverse approaches exist for the characterization and evaluation of deformation behavior in composite materials. In this review, a qualitative description has been given of a number of ongoing studies at Drexel University centered on metal-matrix composites and developed in light of current and predicted materials requirements of the Navy. These studies focus on what are considered to be critical areas in composite materials technology in which the goal is the design, development, and application of improved materials.

The interface provides the direct link in the composite by which stress transfer takes place; its role is understood through a detailed microstructural study in as-fabricated, directionally-solidified or thermally-degraded composites following deformation. The structural observations also allow for a critical appraisal of conformity to or divergence from rule-of-mixtures predictions. Residual stresses control the extent of elastic behavior in composites. These stresses originate from thermal constraints or may be tailored by applying controlled amounts of deformation prior to service. As a consequence, advantage may be taken of residual stresses in order to optimize the properties of the composite in a particular application. Solid state diffusion at interfaces in composites leads to thermal degradation. However, recourse to and selection of coatings on the basis of a firm understanding of the attendant diffusion processes minimizes this problem. Controlled thermal degradation can be utilized in the production of stable structures in composite materials. This involves production of the composite by solid-state reaction to the point of equilibrium. Each of these approaches is of general application to composite materials. Current and future interest is centered on composite materials for high-temperature service.

Acknowledgments

The authors acknowledge key contributions to the composites studies by several former graduate assistants, namely: T. Darroudi, H. P. Cheskis, A. Pattnaik, M. R. Pinnel, K. M. Vedula. Aspects of the composites fabrication, metallography, and testing were capably handled by R. J. Zaehring.

Remote Infrared Sensing of Atmospheric Chemical Reactions

Dr. James N. Pitts, Director of the state wide Air-Pollution Research Center of the University of California, is one of three principal investigators on an ONR project entitled "Solar Activity Variations." Dr. Pitts and one of his graduate students at the UC/Riverside campus, Barbara Finlayson, have been looking at the light emitted by the reaction of ozone with hydrocarbons which contain double bonds. The light output of these reactions is quantitatively related to ozone concentration. The technique promises to detect ozone concentrations as low as 0.01 part per million. Finlayson and Pitts identified one of the intermediate species in these reactions as the hydroxyl radical (OH). This species is known to emit radiation in the visible and infrared spectral regions. Light emission in the infrared (down to a wavelength of 4 microns) had not previously been suspected in chemical reactions which involve ozone and hydrocarbons. All types of double-bonded hydrocarbons appear capable of participation in this reaction.

The purpose of the atmospheric chemistry task of this ONR project has been to develop techniques for remote sensing of atmospheric chemical species (especially in the troposphere) by means of the visible light emitted in various reactions. The surprising and significant finding of this study is that some reacting

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NRL Investigates Shipboard Hazards

Fred Saalfeld
Naval Research Laboratory

Combustion in Confined Spaces

Loss of life and decrease of combat capability due to shipboard fires continue to be critical problems to the Navy—as evidenced by the ENTERPRISE and earlier disasters. Yet, there is a decided lack of information on the nature and quantities of products formed in fires, particularly as related to toxicity, to further fire spread and to other damage, especially under conditions of limited or no ventilation as is so common in the Navy where fires often occur in confined spaces.

Knowledge gained from research in this area will lead to more judicious choice of products and procedures to minimize extent of damage, and minimize incapacitation and loss of life from exposure to and breathing of such atmospheres, through better protective techniques.

The objective work is to determine the nature, amounts and conditions under which toxic and lethal agents are produced by fires in confined spaces, including determination of (a) effects of variables such as burning rates, types of combustibles and reduced oxygen concentrations or formation of both gases and smokes, (b) the ability of such smokes to absorb and transport irritant and toxic products, and (c) the role played by thermally degradable but nonflammable materials in toxic product formation.

Both liquid and solid combustibles, of types prevalent aboard ship, were used as the experimental fuels for this study. Since the role of decreasing oxygen concentration on the rate of burning and its effect on the nature and quantities of the by-products of combustion are of special interest, a considerable portion of the experimental studies were carried out in closed vessels. By maintaining the internal pressure of these vessels at one atmosphere, shipboard compartments can be simulated. Toxic products, including CO, HCl, HCN, SO_2, nitrogen oxides and organic vapors, were detected and determined quantitatively as well as the increase of CO_2 and the decrease of O_2 concentration.

The examination of smokes from combustion processes involved four principal areas of effort: (1) the generation, collection, and storage of smokes from selected materials, (2) examination of the physical and chemical nature of these smokes, (3) investigation of their potential for transport of toxic gases, and (4) assessment of controlling combustion parameters upon the nature of smokes generated. Yields and properties of these smokes will be related to their roles in complication of the hazard and control of fire in confined spaces.

Analysis of Gases Dissolved in Seawater

The Navy and oceanographic science in general need the capability for rapid, automatic, continuous analysis of seawater by methods which are suitable for shipboard and/or *in situ* operation. This is particularly true for certain dissolved gases and other chemical compounds (*e.g.*, O_2, CO, CH_4, heavy petroleum products, detergents, and pesticides) which may undergo relatively large changes in concentration with depth and time. Because of its own role as a contributor to marine pollution, the Navy can serve its own interest by acquiring and maintaining in-house capability for assessing such pollution, particularly in coastal areas in the vicinity of naval bases. Meaningful assessment of pollution caused by the Navy requires accurate baseline data for these areas. Successful completion of this research will provide and maintain that capability, as well as the capability for shipboard and *in situ* analysis of nonpollutant dissolved gases. The latter gases are of importance to the Navy in regard to prevention of corrosion of underwater structures, assessing the relationships of dissolved gases to acoustic properties of seawater, chemical tracing of water masses, and man-in-the-sea programs.

The general purpose is to develop and utilize instrumental methods for determining the distributions of gases and other compounds in the marine environment, to interpret these distributions, and to extract information which will be of operational value to the Navy. Specific objectives are given below:

a. To measure CO and CH_4 in the atmosphere and surface water at the air-sea interface. It is the purpose of this study to determine whether the ocean is a source or a sink for the above gases. In order to understand the role of the ocean in the geochemistry of these atmospheric pollutants, such a study is necessary.

b. To measure low-molecular-weight hydrocarbons in the ocean and determine their relationship to biological activity. This is a joint project with the Marine Biology and Biochemistry Branch to ascertain the origin and natural variation of hydrocarbons in the ocean. This information is needed now to serve as a baseline for any meaningful study of hydrocarbon pollution in the marine environment.

c. To conduct laboratory studies of the production of CO and light hydrocarbons in salt water containing dissolved organic carbon and/or marine organisms. This is another joint project with the Marine Biology and Biochemistry Branch, and it is auxiliary to objectives (b), (d) and (e).

d. To measure medium- and high-molecular-weight hydrocarbons as well as other organic chemical pollutants in ocean, bay, and river waters. These measurements will be related to standard biological parameters used in designating polluted waters.

e. To measure CO and nutrients in and near scattering layers in the ocean. The cause-and-effect relationship between marine biota and scattering layers is unresolved. Do marine organisms actually create a scattering layer, or do they simply respond to it? Since organisms consume nutrients and produce CO, determination of the temporal behavior of these constituents in and near scattering layers should help to resolve the ambiguity. The knowledge to be gained may be of operational value to the Navy. For example, the ability to induce or dissipate scattering layers by chemical means would enhance the Navy's capability in acoustic surveillance and camouflage.

f. To measure atmospheric CO and hydrocarbons at various altitudes by using the NRL aircraft. These measurements will be used in conjunction with (a) above.

g. To develop a technique for separating hydrocarbons above C_7, alcohols, amines, and organic acids from seawater by a sparging technique for subsequent analysis by gas chromatography and mass spectrometry.

h. To develop the capability for continuous, *in situ* monitoring of dissolved gases in seawater. Such capability would be very useful for general survey purposes and for specific search efforts (*e.g.*, detecting hydrocarbons from a sunken vessel). It would also benefit the man-in-the-sea program, particularly in regard to the goal of extracting breathing gas from seawater.

i. To develop a method using a gas chromatograph-mass spectrometer combination for identifying and measuring higher hydrocarbons and pesticides.

NRL-developed equipment and commercial gas chromatographs with appropriate modifications are being used to achieve the objectives listed above. Our group is responsible for the development of gas chromatographic techniques presently in use by most Navy laboratories as well as by most nongovernment oceanographic institutions. Approaches to the specific objectives above are now considered.

The environmental and associated studies described in objectives (a) to (g) are being conducted by our previously developed methods. Some of these studies are in conjunction with the Marine Biology and Biochemistry Branch. A new, commercially available instrument will be used on shipboard and in NRL aircraft for continuous monitoring of atmospheric carbon monoxide.

The approach to continuous, *in situ* monitoring of dissolved gases is based on diffusion of these gases through a supported silicone membrane into an automated gas chromatograph which is either enclosed in a towed pressure housing or installed in an underwater habitat or submersible vehicle. Relative changes in concentration would be detected easily, but absolute calibration would require comparison to periodic hatch analysis.

A semi-continuous sampling system is being developed. This system will employ a counter-current gas-water technique and should prove useful for monitoring oil spills and polluted waters.

Analysis of Hyperbaric Atmospheres

The Navy, in its deep sea research program, needs the capability to provide and maintain for various periods of time healthful atmospheres in deep submersibles, undersea habitats, and manned pressure chambers. This task should contribute vital elements to the production and maintenance of a safe atmosphere in deep submersibles from the standpoint of both the health and effectiveness of the personnel involved and the reliable operation of equipment. Providing a safe and healthful atmosphere requires the control of trace contaminants as well as the obvious necessity for maintaining the proper O_2 level and removing CO_2. The present knowledge of CO_2 absorption by solid chemicals from air has been obtained mostly at atmospheric pressure and ambient room temperature. The use of these absorbents in high pressure environments reduces the diffusion rates of gases and increases the specific heat/unit volume of gas. Both of these factors influence the efficiency of absorption, and low temperatures reduce the volatilization of the water formed and decrease reaction rates. Thus, the extrapolation of present data to increased pressures and lower temperatures cannot be done safely.

In several instances aboard nuclear submarines and in undersea habitats, the effectiveness of personnel and the operation of equipment have been impaired by the presence of trace quantities of organic compounds or carbon monoxide in the atmosphere. As man becomes subjected to atmospheres at higher and higher pressures, the detection of contaminants becomes increasingly difficult because of their high dilution with inert gas, although their partial pressures remain the same. This is physiologically significant. Therefore, toxic contaminants in an atmosphere must be detected at an early stage and at very low concentrations so that steps can be taken for their control before they reach a level that jeopardizes the success of the operation.

Gas chromatographic techniques, which have been successful in past analysis by NRL of nuclear submarine and SEALAB II atmospheres, provides the primary approach toward monitoring trace contaminants in the atmospheres of hyperbaric systems. Highly sensitive chromatographic detectors for CO were used successfully at the Laboratory with pressurized samples of SEALAB II air.

Two approaches were used for the CO_2 absorption study: (1) a bench method where small samples were studied under pressure with expansion of the gases to atmospheric pressure with wasting of the gas, and (2) forced ventilation in a hyperbaric chamber. The effectiveness of the gas expansion technique has obviated the need for a hyperbaric facility, unless pressure data are needed above 20 atmospheres.

Analysis of Submarine Atmospheres

The determination of trace contaminants of submarine atmospheres has for many years been an active effort at NRL. No single instrument has been developed that can characterize all known contaminants. Among the many techniques used aboard submarines for atmosphere analysis are: infrared spectrometry, gas chromatography, thermal conductivity measurements, mass spectrometry, gas chromatography/mass spectrometry, and a special gas chromatograph with a microcoulometer detector. This latter technique is sensitive (from 10 ppb to 10 ppm) to all halogen-containing organic compounds except fluorides and permits the quantitative characterization of an enclosed atmosphere.

An example of how successful these analytical techniques have been is the increase in the length of time a submarine can remain submerged. When nuclear submarines were first built the contaminant loading of the atmosphere was the determining factor in the ship's submergence time. Now, the management of atmospheric contaminants has improved to the point that the ship's underwater endurance is determined by logistical problems.

On the Naval Research Reserve

NRRC 11-2

NRRC 11-2 recently participated in the grand opening ceremonies for the new Los Angeles Trade and Convention Center located in downtown Los Angeles.

The grand opening was, in effect, a small trade show. Displays were set up and manned by a wide cross section of both State and Federal Governmental agencies as well as private industry.

ONR sent a display model of Alvin, its Deep Submergence Research Vehicle (DSRV). This was a large, attractive, fully animated display model. Individual telephones, located at the front of the display, provided a convenient means for listening to the DSRV story while watching a simulated resuce being performed by Alvin.

Members of the NRRC 11-2 were on hand to answer questions from visitors.

A number of the members of our unit were able to go on ACDUTRA at their mobilization billets. In addition one member of the unit attended the Nuclear Weapons school at Sandia Base, Albuquerque, New Mexico, where he received basic indoctrination on the theory and operation of all of the atomic weapons presently in the Navy Arsenal.

NRRC 11-5 Activities

NRRC 11-5, San Diego, California, has a variety of scientific expertise. The weekly lectures include topics in the fields of nuclear physics, medicine, oceanography, biology, chemistry, ecology, sociology, international relations and leadership.

The men of NRRC 11-5 are leaders in the local scientific community. During the past year, more than 10 technical papers were presented by the individual officers; a "Littoral Water Use Study," was also conducted concurrently with their scheduled training program. Beginning with San Diego harbor and coastal waters, the study is aimed at developing a technique and computer code which will make real time data available concerning the ocean depth, bottom condition, traffic, *etc*. Looking ahead, a comprehensive code could evolve from such a program such that ocean activities (conditions) occuring in a given area may be available for navigational aid. Coastal conditions near harbor approaches, of course, are of major strategic importance.

Several officers of Research Reserve Company 11-5 are principals of major industrial research programs which have social as well as military significance. For example, one member of the unit is involved in the development of advanced materials for reusable hypersonic cruise vehicles for space transportation systems. His current research includes the use of low-energy level beta emitting radionuclide to measure coating life on reusable thermal protection systems for earth-orbit shuttle. A second member completed a tour as United States delegate to the International Union of Geodesy and Geophysics in Moscow, USSR, where he presented a paper on work supported by the Office of Naval Research, "Convection Induced by the Evaporation of Sea Water."

News Release NRRC 11-7

Plans to increase the 'visibility' of the Research Reserve will be given priority in planning future training schedules for NRRC 11-7. Two events now in the planning stage will get this new approach to training underway during the third and fourth quarters of the current fiscal year.

Captain James Kay, Jr., Commanding Officer NRRC 11-7, in conjunction with Commander David P. Van Ort, (D.C.), and Commander G. V. Brown, Commanding Officer NRGC 11-8 (S), is planning a special program of interest to medical personnel. All medical personnel in the Tucson Area will be invited to attent. The format of the meeting will feature a joint training session with a group of medical officers seeking to establish a Naval Reserve Medical Company. Commander David P. Van Ort, (DC) is the prospective commanding officer of this new reserve component. The program for this training session will deal with research in hospital administration and/or management. The program will be planned and conducted by Commander Daniel Capps, Administrative Officer of NRRC 11-7. In civilian life Commander Capps is the administrator of the recently-opened multi-million dollar teaching hospital at the University of Arizona. One objective of the joint meeting is to assist in the recruitment of officers with medical research backgrounds as members of the Research Reserve.

Also being planned is a training session to deal with the Naval Science Cruiser Program for 1972. The 1971 winner of the Navy Science Cruiser Award will discuss the research and scientific principles of his project, "An Electronic Conditioned Reflex Machine." Classmates and faculty advisors will be invited to participate in the training session as an effort to enhance the recognition given to Science Cruiser Award and, of course, promote visability of the Research Reserve Program.

In 1971, officers of NRRC 11-7 assisted officials of the Southern Arizona Regional Science Fair by reviewing entries for the Science Cruiser Award, by selecting the winner and alternate winner, and by presenting the award at the close of the fair.

NRRC 11-11 Reports

Officers of NRRC 11-11, Santa Monica, California recently participated in the Orange County Science Fair in conjunction with the Navy

Science Cruiser Program. Upon the Fair's conclusion, LT R. D. Wilson of NRRC 11-11 presented the Navy award to the winner.

Officers of NRRC 11-11, Santa Monica, California were jointed by officers of Naval Reserve Engineering Specialist Company 11-5 in a recent visit to the Pacific Missile Range, Point Mugu, California. They were briefed on the mission of PMR and the Navy Astronautics Group. In a tour that followed, a variety of Navy missiles and operational aircraft were inspected. Arrangements for the drill were made by LCDR R. L. Nifong, a member of NRRC 11-11.

In order to broaden the scope of its training programs, joint meetings are scheduled with Reservists of Naval Engineering Specialist Company 11-5 and Defense Contract Administration Services Region-Los Angeles. This not only provides a means of keeping abreast with research activities of interest to other Navy organizations, but of the Air Force and Army as well. It also results in a larger audience for the many outstanding speakers that have come before the unit. During the past year members of the Company have been briefed on such important topics as the B-1 Aircraft Program, The Effects of Nuclear Power on the Environment, Navy Research in Pollution Abatement, the LHA Amphibious Assault Ship Program and the Mariner-Mars Program. Lieutenant G. Hagen is the Training Officer of NRRC 11-11.

(Continued from Page 15)

species emit not only in the visible but also in the infrared spectrum. These species might be encountered in the ozone—rich layers of the stratosphere as a result of combustion products released by jet engine exhausts or rocket plumes. The chemiluminescence experiment at Riverside implies that rockets and aircraft operating in the stratosphere may be detected by infrared sensors observing their exhaust products. Plume detection is an attractive alternative to vehicle detection because of the large trajectory area involved. The chemiluminescent reactions involving ozone are more efficient at low atmospheric pressure and should emit light for times as long as several minutes.

NRL Scientists Examine Liquid Crystals

Scientists know that some organic compounds pass through a molecular intermediate state between a liquid and a solid. In this state, these compounds exhibit certain unusual physical properties such as optical birefringence and viscous flow, thus they have been called liquid crystals.

Naval Research Laboratory (NRL) scientists here are studying the various possible scientific applications of liquid crystals, one of which is temperature sensing. They say this thermal sensitivity may prove to be an important method for diagnosing skin cancer, since normal and cancerous tissues differ slightly in temperature.

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Research Notes

NRL Parlays Nuclear Reactor into Multimillion Dollar Saving

There's not much of a market these days for used nuclear reactors.

Most often, they're either torn down or abandoned as the rapid pace of technology relegates them to oblivion.

But at the Naval Research Laboratory (NRL), the old water-immersed reactor facility has taken on a new career as a well-insulated acoustics research pool.

Since acoustics is one of NRL's primary mission areas, the pool will provide its scientists with an exceptional research tool which otherwise could have cost them as much as $15 million to fabricate.

Constructed in the mid-1950's as part of a nuclear reactor, the 140,000-gallon pool contains physical characteristics which are particularly useful for up-to-date acoustics studies involving sound wave reflection from objects using ultrasonic (high frequency) sound transmission. Underwater studies are enhanced by massive steel reinforced concrete walls which provide stable supports for two movable bridges over the pool. The steel reinforcing also insulates the water from electrical pickup from outside sources.

The water treatment plant provides both filtration and deionization, yielding virtually distilled bacteria-free water. The deionization process is especially valuable in preventing deterioration of models and acoustic transducers. In addition, the clarity of the water makes possible precise measurement of distances by optical techniques.

Besides the pool, the building itself is extremely useful for other acoustics studies and related work. For example, a high bay area, already in the building, is used for air acoustics studies which when compared with similar measurements in the pool makes it possible to examine the relationship between geometric and elastic effects of acoustic reflection from underwater objects. This information is required if one is to determine from an echo the material of which an underwater object is constructed. NRL acoustics scientists point out that such information could result in improving the Navy's ability to identify underwater objects.

A new research program concerned with the acoustic determination of the properties of liquids and amorphous solids over a wide range of pressure and temperature (3000 atmospheres and 2000°C) has also benefited from the facilities provided for the nuclear reactor.

Of particular value to this research is the presence of a large room constructed with two-foot thick reinforced walls and ceiling which safely contains the pressure "bomb." This room is adjacent to a chemistry laboratory, useful in handling and filling the liquids being investigated (molten metals, glasses and salts), most of which are highly reactive.

This research is designed to provide much needed data for the construction of new and improved nuclear and thermonuclear (controlled fusion) reactors intended to provide for the world's growing need for electrical power. In addition, the glass studies are aimed at the development of low-loss glass light-pipes for use in long-distance optical communication systems. These may someday replace copper wire as a means of transmitting information.

Also at the new acoustics research facility, NRL scientists have developed a technique for investigating and measuring the properties of strengthened glass, which they say will be of great value for the nondestructive rapid determination of glass strength and in the study of the strengthening mechanism itself.

NRL Finds Way to Obtain Sea Spectra Analysis Via Photography

Naval Research Laboratory scientists have developed a new technique which enables them to measure quantitatively the wave height spectra of the real ocean.

The Sea Photograph Analysis (SPA) technique takes advantage of the fact that sufficient information exists in each photograph to unambiguously determine spectral amplitudes over a fairly wide range of ocean wavelengths.

In addition, Denzil Stilwell of NRL's Electronics Division and principal investigator of the technique said the spectra obtained yield the two dimensional directional wave number spectrum of the wave height variations. With such information, it is now possible to obtain a greater understanding of radar and acoustic scattering, in addition to examining wave generation characteristics and wave interactions.

Mr. Stilwell has written a paper on the subject that contains the basic theory of the technique, its limitations and examples of its applications.

R/V LULU Departs for Miami for Research Role

The catamarn R/V LULU, operated by the Woods Hole Oceanographic Institution, embarked today with the underseas habitat EDALHAB on board for a three-month scientific investigation off the Florida Keys and Miami. LULU is the mother ship for ALVIN which is operated by Woods Hole for the Office of Naval Research.

The EDALHAB-LULU combination is a highly mobile habitat system. The scientific value of this mobility will be evaluated during the FLARE project.

Sponsored by the National Oceanic & Atmospheric Administration (NOAA), the project is known as FLARE – "Florida Aquanaut Research Expedition." Beginning January 27 and winding up April 17, FLARE will involve a force of 40 investigators. The major support teams are from the University of Miami, University of New Hampshire, University of Pennsylvania, NOAA, and the Woods Hole Oceanographic Institution. Other participants include the American Museum of Natural History in New York, the Academy of Natural Sciences in Philadelphia, the Los Angeles County Museum of Natural History, NOAA laboratories, Miami-Dade Junior College, Trenton State College, and the University of North Carolina School of Medicine.

The research itself will be concerned with life of coral reef communities, fish behavior related to traps and other fishing gear, chemical composition of seawater, the effects of pollutants on coral formations, and the efficiency of artifical reefs as attractors of marine life.

Teams of two or three marine explorers, all fully trained in diving techniques, among them three women, will be rotated aboard EDALHAB. Each team plans to remain underwater for three to five days, either aboard EDALHAB or Scuba diving nearby in the ten offishore underwater dives.

The Oceanographic Institution research team aboard R/V LULU will be headed by William O. Rainnie, Jr., who will act as FLARE Program Coordinator. Other W.H.O.I. Participants include Barrie Walden, Operations Director; Dan Clark, Operations Consultant, and Captain Dale Butler, Master of the LULU.

EDALHAB – 20 tons, 21 feet long – was modified for the FLARE mission at the Woods Hole Oceanographic Institution by engineering students and faculty members from the University of New Hampshire Engineering Design & Analysis Laboratory. R/V LULU – 460 tons, 98 feet long – was developed originally as the mother ship for deep-diving submersible ALVIN, presently in annual overhaul in Woods Hole.

ALVIN operates independently of LULU once submerged and reaches depths of up to 6000 feet while EDALHAB is a living habitat capable of supporting two or three scientist-aquanauts for up to five days at a depth of 45 feet.

EDALHAB's present engineering design represents a further advance in marine technology because, rather than remaining stationary as before, the cylinder-shaped laboratory can now be transported by LULU to sites of investigation, planted 10 to 40 feet above the study area by anchors, then moved elsewhere, or returned with ease to LULU.

EDALHAB is wholly dependent on LULU for a number of services. Not only does the catamaran transport the hibitat to selected destinations (unlike ALVIN, EDALHAB is not self-powered), LULU also provides facilities and personnel for surveillance of all systems, and even sends meals down by diver-messenger.

Also aboard LULU is a two-compartment decompression chamber to decompress the saturated divers after their mission or to stabilize divers from the habitat during a change of location. The chamber and the communications system were both designed by the University of New Hampshire engineers.

EDALHAB's aquanauts will be jammed into work space measuring 10 by 8 feet – with the barest essentials for subsistance – two bunks, a portable cot, a lab bench, a desk, a sink with exhaust hood, telephones connecting with LULU, a video camera for Rainnie's teams above on LULU to continually observe and insure the safety of EDALHAB's occupants, and three Scuba-type escape bottles with regulators.

Equipped to carry a scientific team of 15 and a crew of 11, R/V LULU can sustain a speed of 6 nots for 1,200 miles, carries radio, radar, sonar, and an auxiliary power boat. She was built by the U.S. Navy in 1964, designed specifically for operation by the Woods Hole Oceanographic Institution, and is owned by the Office of Naval Research.

William O. Rainnie, Jr., FLARE Program Coordinator and LULU team chief, is a graduate of the U.S. Naval Academy, Annapolis, and the U.S. Naval Submarine School, New London, Connecticut. He joined the Woods Hole Oceanographic Institution in 1961, where he presently heads the Deep-Submergence Engineering and Operations Section of the Ocean Engineering Department.

Barrier Walden, who played the major role in engineering and coordinating the EDALHAB program at Woods Hole, will be Operational Director on the scene. A native of Needham, Massachusetts, he attended Rensselaer Polytechnic Institute and Florida Atlantic University, receiving his B.S. degree in 1969. He joined the Oceanographic Institution at Woods Hole the following September and is a Research Associate with the Institution's Department of Ocean Engineering.

Use of EEG for Predicting Performance Studied

The Office of Naval Research has initiated a program to study the possibility that a person's electrical brain waves may be measured to help predict performance in the service.

The Navy, which customarily tests recruits for potential performance capability, is interested in this new technique as a supplement to present paper-and-pencil tests. Since a brain wave testing system would not depend on language, it would help eliminate bias in evaluating Navy recruits who are drawn from a widely different cultural background.

Studies using brain wave records (called electroencephalograms or EEGs) as a means of gaining information on an individual's mental capability have been performed at the Langley Porter Neuropsychiatric Institute, San Francisco, under the direction of Dr. Enoch Callaway, and supported by the Office of Naval Research, as part of a research program designed to shed light on relations between brain waves and behavior.

This work, together with studies by other research scientists, has indicated that a special EEG procedure might be useful in evaluating a person's basic mental functioning and hence help in predicting performance. As a result, the Naval Personnel and Training Research Laboratory, San Diego, in cooperation with the Institute in a program funded by ONR has started experimentally testing a sample group of recruits with this new procedure.

Recruits who have been tested on Navy aptitude tests will also be tested using the new procedure. Their careers will then be monitored for the next few

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years to determine whether the new measures combined with more conventional test results can aid in predicting success or lack of success in future performance.

The technique used in this procedure differs from the conventional electroencephalogram in that a computer is used to detect specific brain responses. The subject is given simple stimuli such as flashes of light or brief sounds. These stimuli evoke brain electrical potentials, and since these brain electrical responses are best seen by averaging on a computer, these brain responses are referred to as averaged evoked potentials (AEP).

If these AEP measurements prove to be valid, they should help to identify recruits who are likely to succeed but who have been inaccurately labeled potentially poor performers by conventional tests. Indications are that a brain wave testing system can be operated economically.

(Continued from Inside Front Cover)

4. *Tick biochemistry.*

Current studies of the physiologic chemistry of ticks have yielded a great deal of information. This information will be used in the near future in establishing tissue cultures from ticks in cooperation with the Rocky Mountain Laboratory. Such tick cultures will allow evaluation of epidemiologic and transmission factors of disease at the vector cellular level and provide ideal media for the isolation of more new arthropod-borne virsuses.

Other accomplishments include disease vector mapping which provides information on the geographical distribution of arthopod disease vectors; a bibliography of ticks and tick-borne diseases; as well as a redescription of *Haemphyselus* genus of ticks including species from all parts of the world.

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IN THIS ISSUE

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Growth of Al_3Ni (fiber)—aluminum (matrix) composites by interdiffusion in an initial structure formed by hot pressing alternate layers of nickel wires and aluminum foils. Here the composites are hot pressed plus 600°C for 2.5 hr. 100x. *See page 14.*

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