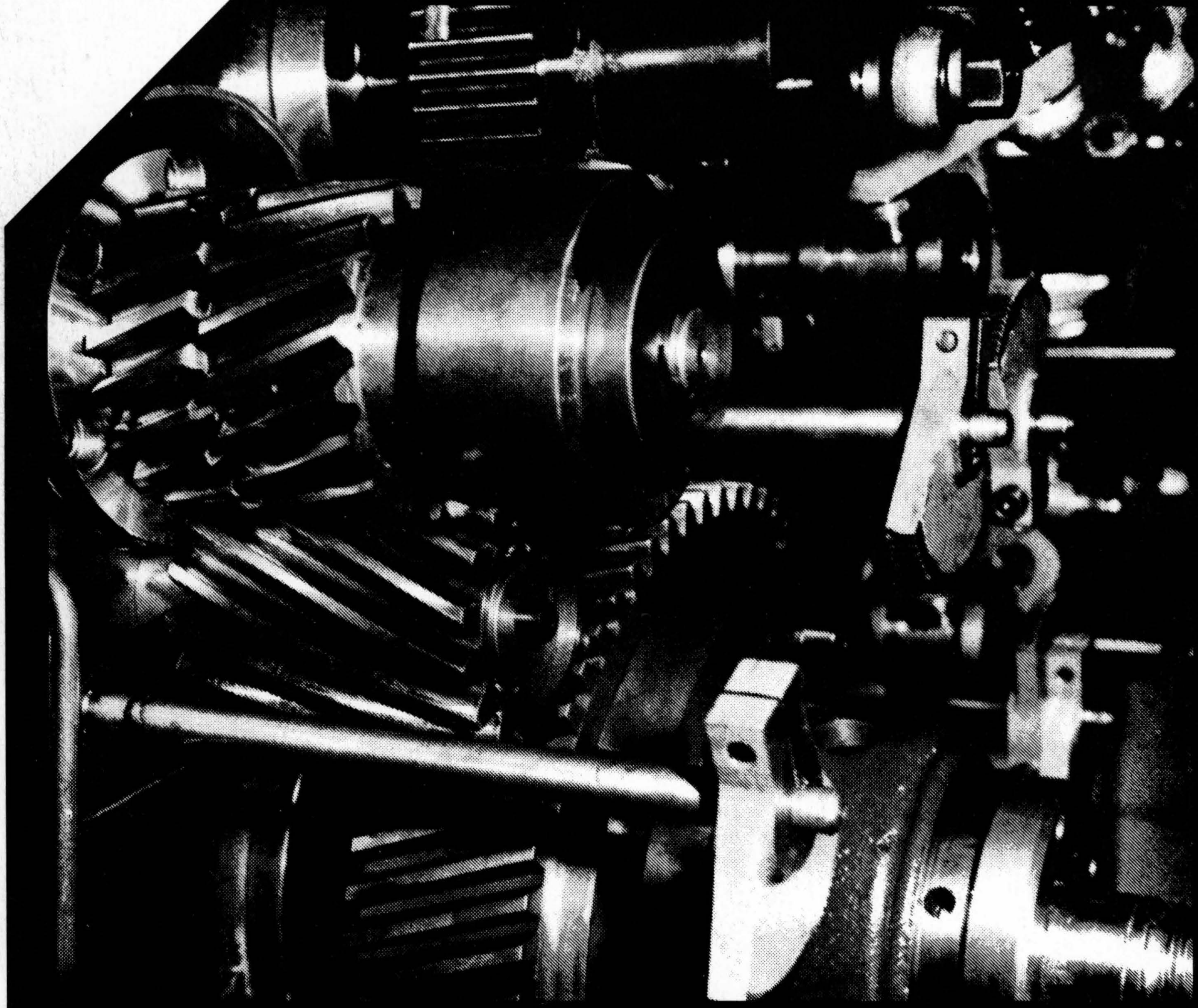
SPECIAL EDITION

Engineers' Forum

VIRGINIA TECH MARCH 1985



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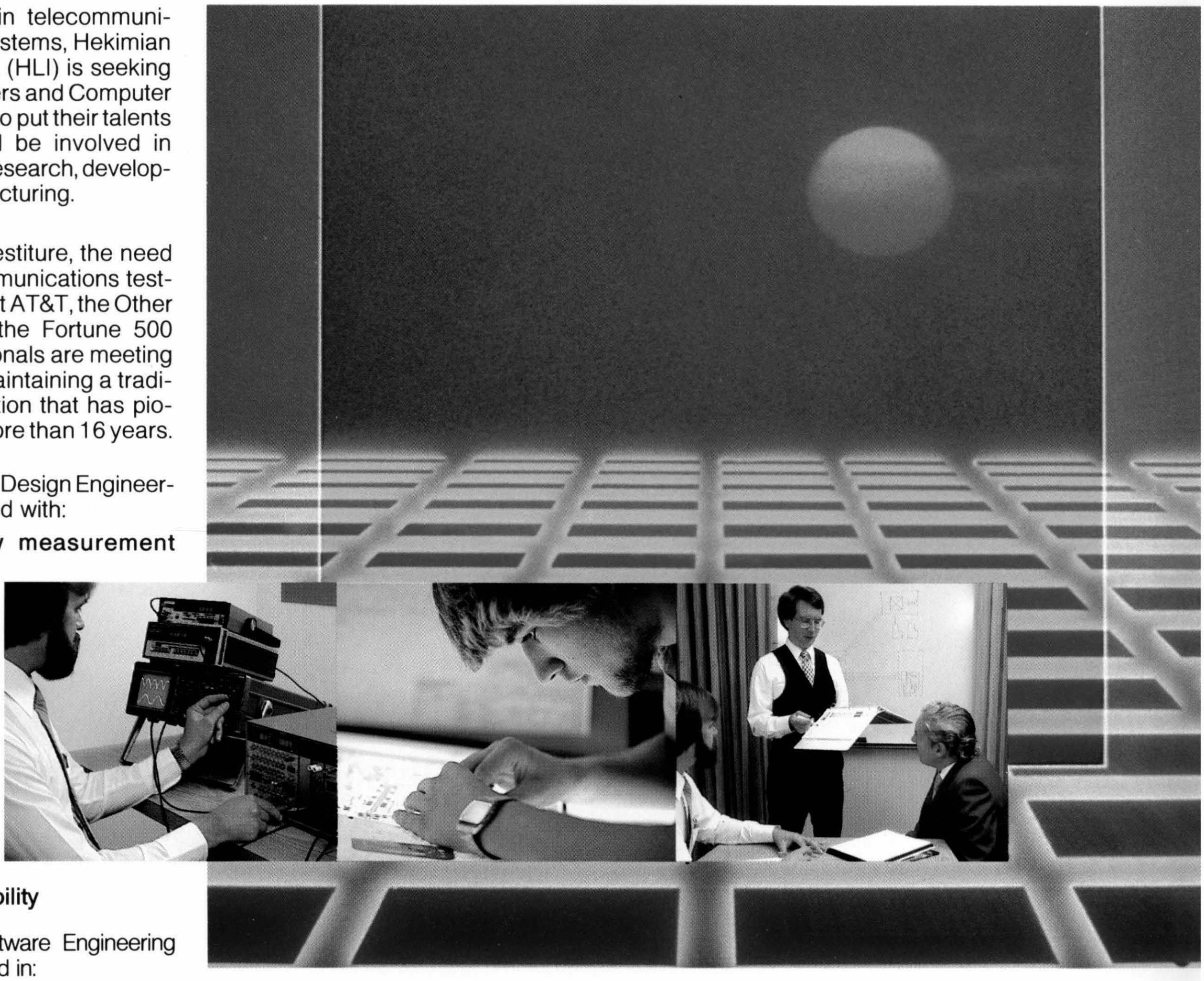

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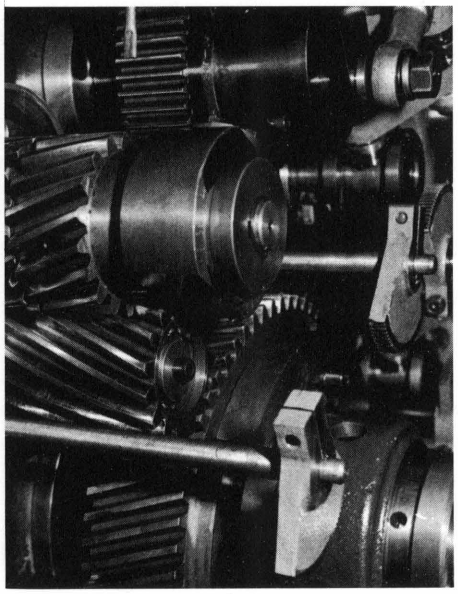

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Drive wheels of the Rapida SRIII printing press used in the production of the *Engineers' Forum.*

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Engineers' Forum

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Editorial

The Engineer and the Piece of Paper

At one end of the table sat the engineer. Painted in shadow, the lined white loose-leaf rested in front of him, unmarked. In his mind, the words hesitated, wedged somewhere between lips and fingertips. Yet, by and by, the graphite flitted up and down, left and right, until soon most of the page had been smudged with a dull carbon pattern -- so that from a distance its whole appeared grey.

What the engineer recorded on that rectangle of paper matters little. I mention it only as an illustration. Maybe by the time he got to the bottom of the page, the part of his brain devoted to vocabulary somehow, frustratingly, veered from the path his creative abilities had been in the process of forging, in which case a hard day might have turned into night as a crumpled idea burned into ashes. It is not important. What matters is that the engineer in the little scenario crossed a momentous threshold: a bridge that took his thoughts, his ideas from the complex metaphysical reality of his mind, to the simple physical ideality of his environment, where straight lines and primary colors constitute all that is possible to be understood. Without that bridge he would have been no more an engineer than would a spider, which builds a marvelous intricate structure of the most exquisite composite "technology," yet is incapable of communicating.

To the right eyes, paper is a windtunnel. Instead of engines powerful, enormous, and costly, however, mere hair and marrow -- mere people -- breathe life into its cavernous gullet. Unmortgaged for the staggering price of a sandwich, an eon later the next "operator" may find its simulations as true as had the first. All of these things to its credit, and yet on too often an occasion a breeze will merit more attention than its subtle currents to an engineer.

Because we say and repeat to ourselves that we are engineers -- as opposed to anything else that walks on two legs -- we tend to distance ourselves from much reeking of What is not Engineering. Sometimes our reasoning seems to be that it is our job to create, to fabricate -- and that, therefore, our creations and fabrications alone should represent ourselves as engineers. How can a true engineer claim to stand on paper when the true engineer stands on a strip of icy cold, weatherbeaten steel I-beam flange?

There is a place for that sort of acceptance of responsibility. It is good. It is noble. All the same, when we call ourselves engineers, should we not ask ourselves what it is that we engineer? And is it not tangible, physical objects -- things whose edges can be scrutinized from all angles, things whose faces can be touched and grasped? Then to divorce ourselves from writing is to divorce our nebulous engineering ideas from our concrete engineering constructs -- writing is nothing more than the bridge that must be crossed to get from here to there!

In the following assemblage of pages, the reader will find four good examples of what an engineer can do on this rough terrain called writing. It is, in a sense, our windtunnel, and I suggest that our mastery of engineering will remain incomplete until we really become engineers, too,. of the paper . . .

Mark Moran

Editor's Page

Engineers' Forum presents the Winners' Issue for the 1985 Technical Writing Competition....

Sponsored by Hekimian Laboratories of Bethesda, Maryland, the annual Technical Writing Competition is intended to offer promising young members of the engineering community the opportunity to demonstrate their talent in the guise of a formal piece of hardcore technical writing. This issue thus represents a number of firsts for *Engineers' Forum*: the first use of a monetary incentive ($250 worth in all) to write, the first table of contents listing just about entirely non-staff members, and the first departure from the conventional quarterly publication format. We the staff of *Engineers' Forum* would like to thank our sponsor Hekimian Laboratories and our esteemed panel of judges whose names follow -- for contributing so graciously to the success of this first, hopefully, of many competitions:

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Lynn Nystrom, Director of News and External Relations, College of Engineering

Rules for 1984-85

1. Entries must deal with a technical aspect of engineering.
2. Entries must be understandable by the general engineering community.
3. Entries must be typewritten, double-spaced, 5-8 pages long, and must include all illustrations.

Rules for 1985-86

1. Entries must deal with a technical aspect of engineering.
2. Entries must be understandable by the general engineering community--i.e. do not include full pages of mathematical formulas.
3. Entries must be of single authorship.
4. Entries must be at least 1500 words long, but *not* to exceed 2000 words (5-8 pgs.).
5. Entries must be typewritten, double-spaced, and must include an abstract and all necessary graphs, diagrams, etc.
6. Entries must be revised upon request.

For further information, come by 112 Femoyer Hall or call 961-7738.

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Ultrafiltration: The Theory and Industrial Applications

Deborah A. Baum

Ultrafiltration (UF) can be described as a membrane separation process which can be used to purify, concentrate, and isolate macromolecular solutes and/or colloids from their solvents. As seen in Figure 1, a solution under pressure flows over a supported membrane surface. Under the influence of the pressure gradient, the solvent and certain small solute particles are colected as the permeate, or ultrafiltrate. The other solute particles are too large to pass through the membrane, and are recovered in an upstream chamber as the retentate, or concentrate. The range of particle sizes that the semipermeable ultrafiltration membrane can isolate from the surrounding medium is approximately ten to 100 Angstroms. The types of compounds separated with ultrafiltration are high molecular weight solids such as proteins, natural gums, and polymers, and colloids such as clays, pigments, minerals, latex particles, and microorganisms.

The first thoughts for the use of ultrafiltration as a large-scale industrial process came in 1963, when Amicon Corporation and Door-Oliver Company collaborated on the development of an economical process to remove colloidal and macromolecular impurities from secondary sewage effluent. Although the process was never made economically feasible, the collaboration led to widespread interest in ultrafiltration for other purposes.

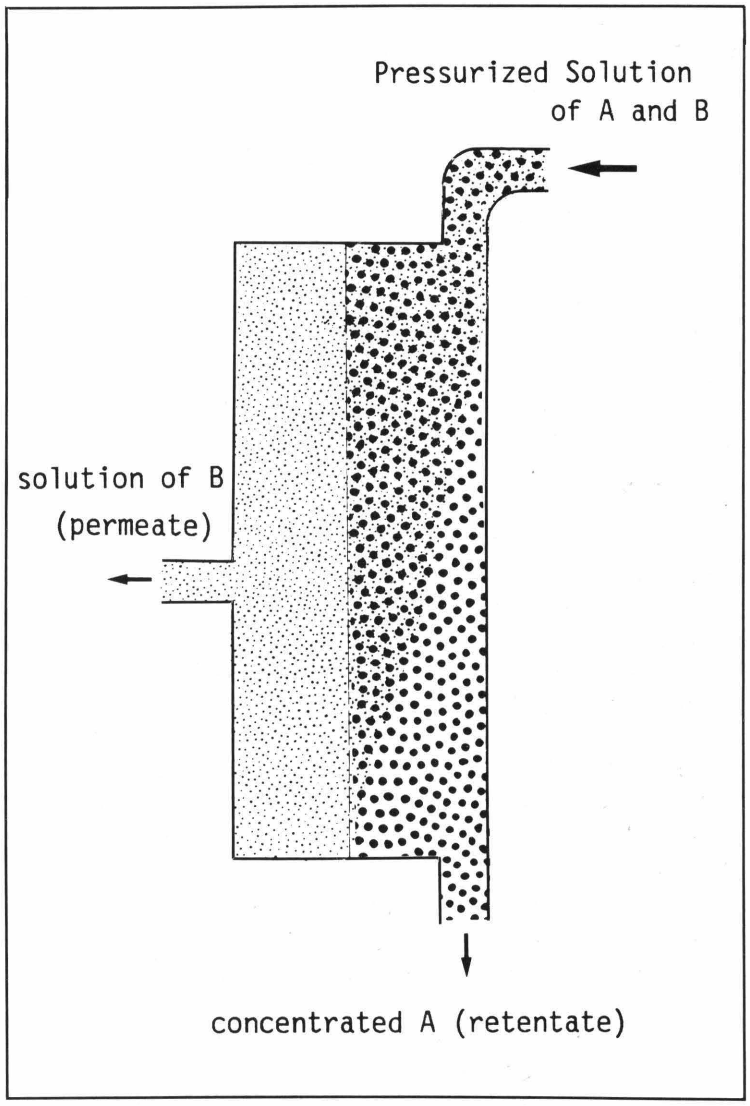
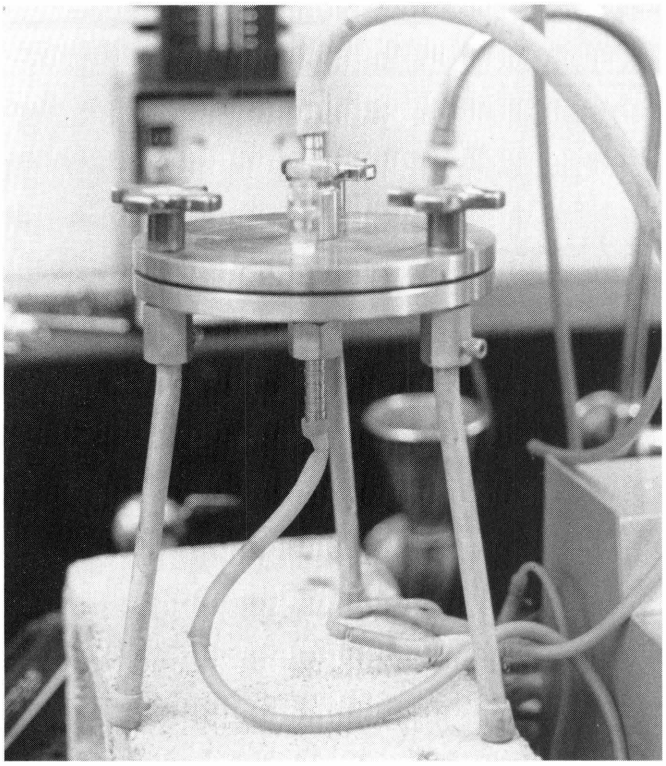


Figure 1: Schematic diagram of membrane ultrafiltration process



This filter press from the Biochemical Engineering Laboratory can be used for Ultrafiltration.

The first big success for ultrafiltration was the recovery of paint colloids from the electrocoating process; electrocoating is the defect-free application of paint to metals by electrophoretic deposition. Ultrafiltration proved to be able to recover the paint colloids more economically than any other process. In addition to saving money on paint, the users of the ultrafiltration process had noticeably less pollution. The successful use of ultrafiltration for paint recovery, coupled with the invention of better membranes through the 1960s and 1970s, has led to more and more people utilizing ultrafiltration as an industrial process.

Ultrafiltration has many general advantages when compared to competing, traditional separation processes[4,15]:

1. Ultrafiltration can operate at select temperatures which will avoid thermal and oxidative degradation of the desired product.

2. There is no phase change associated with ultrafiltration as there is with freeze-drying or evaporation processes; this helps avoid the collapse of gels and the breaking of emulsions.

3. There is a constant ionic strength and pH in the concentrate.

4. Ultrafiltration is versatile in carrying out more than one function at a time, such as simultaneous fractionation and purification.

5. Ultrafiltration is economical in both small- and large-scale operations.

6. Because there is no phase change, ultrafiltration requires no heat or chemical additions; the only energy requirement is the compression energy of the feed.

Theory:

To understand the industrial process of ultrafiltration, it is important to understand some of the mass transfer theory of ultrafiltration.[3] (Figures 2-4)

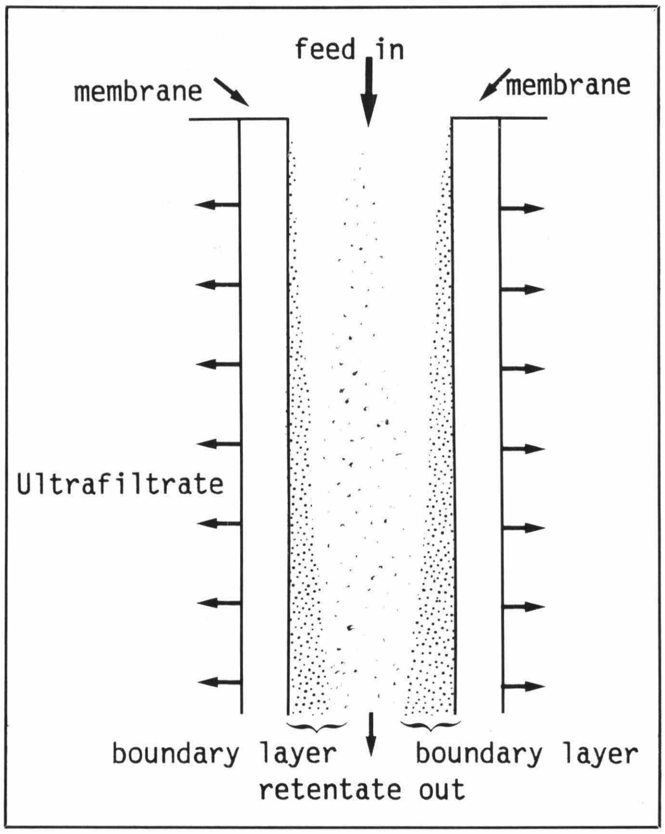


Figure 2: Development of the polarized boundary layer

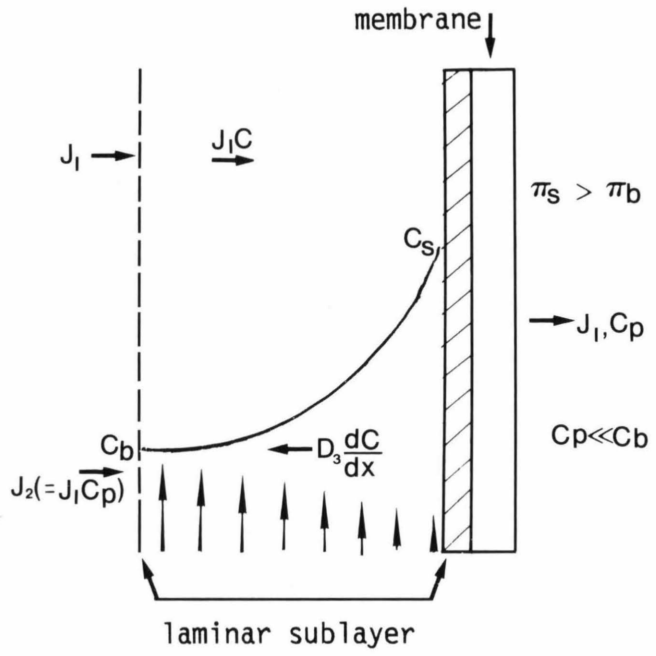


Figure 3: Polarization in Ultrafiltration

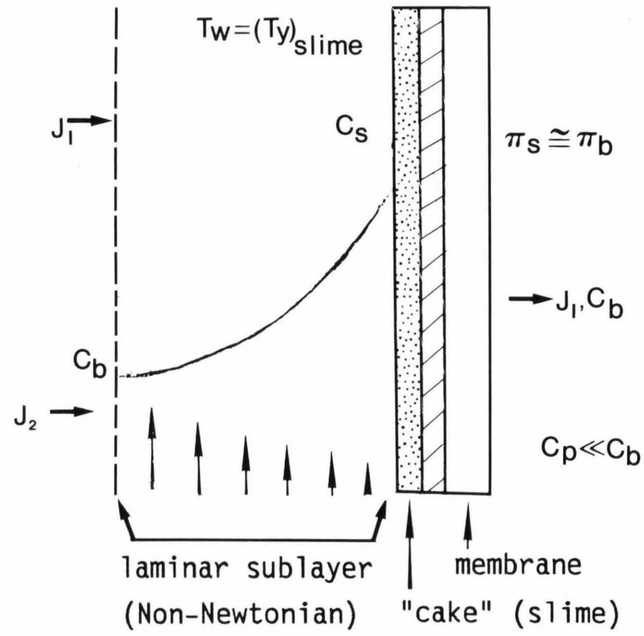


Figure 4: Gel polarization in ultrafiltration

Concentration polarization:

Local steady-state mass transfer of solute requires that the rate of convective transport of solute toward the membrane surface be equal to the rate of convective and diffusive transport of solute away from the surface. This is possible only if the solute concentration in the boundary layer next to the membrane surface (Cu) is higher than the concentration in the bulk (C_6). This phenomenon is known as concentration polarization. The governing equation for mass transfer in this case is derived from Fick's Law and the Continuity Equation. A solute balance, neglecting axial concentration gradients and at steady-state and isothermal conditions, yields:

$$J1 \left(\frac{C_A}{C}\right) + Ds(dC_A/dx) = 0 \qquad (1)$$

integrating:

$$J1 = Ks*\ln(Cw/Cb) \qquad (2)$$

where: Ks = mass transfer coefficient

Ds = diffusivity

J1 = solvent flux

C_A = concentration of A

C = concentration

Gel polarization limitation:

When solutions of macromolecular solutes are concentrated by polarization, a "slime" or "gel" layer builds up on the surface of the membrane. The gel is a Non-Newtonian fluid that does not move. In essence, it acts as a secondary dynamic membrane, in addition to the resistance of the membrane itself, which also offers resistance to the flow of solvent.

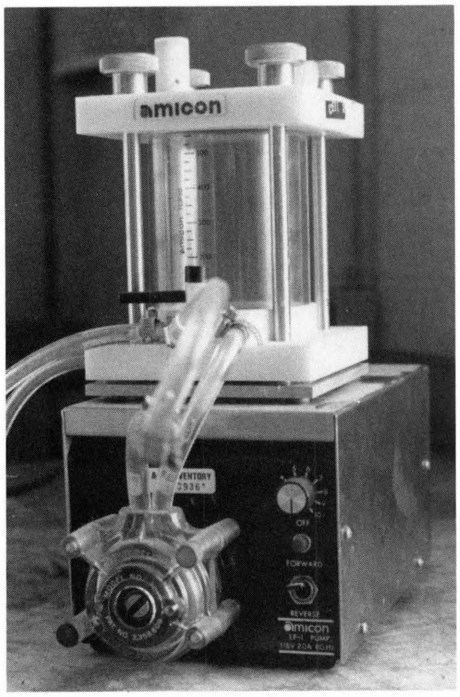
To have gel formation, the rate of convective transfer of solute must be greater than the back transfer rate. This increases the concentration of the species at the surface of the membrane until a limiting concentration is reached when further concentration cannot occur due to the impermeability of the polarized macromolecular layer to other macromolecules. This limiting concentration is the gel concentration, Cg. The gel layer reduces the solvent flow until the reduced convective forward transfer of solute equals the diffusive back transfer of solute. A solute balance, neglecting axial gradients and at isothermal, steady-state conditions,yields:

$$J1\left(\frac{C_A}{C}\right) + Ds(dC_A/dx) = 0 \qquad (3)$$

integrating:

$$J1 = Ks*\ln(Cg/Cb) \qquad (4)$$

This reveals two very important facts. First, the ultrafiltrate rate at steady-state is controlled by the rate at which the species can be put back into the bulk flow from the surface. Therefore, higher stirring rates or higher shear rates should be used to increase the flux. Second, changing variables that increase the flux without increasing back transport of the species into the bulk will not give an increased steady-state flux. Thus, increasing the pressure difference will only cause a greater buildup of gel, and the rate of flux will not be increased.



This is the Ultrafiltration device from the Chemical Engineering Unit Operations Laboratory.

Membranes:

The typical ultrafiltration membrane is an asymmetric two-layer structure. Asymmetric means that the pore radii are smallest at the surface and increase outward. The side that contacts the pressurized feed consists of a skin layer, approximately 0.2 micrometers thick, which contains the micropores at which the separation occurs. The remainder of the thickness, approximately 100 micrometers, is a microporous spongy sublayer, which acts as a support for the skin.[2]

Today's membranes, usually polymeric films, can withstand high pressures and temperatures, abrasive fluids, organic solvents, and do not become plugged or fouled because of their asymmetry.

Problems Associated with Ultrafiltration:

There have been two major problems associated with ultrafiltration. The first problem was the internal fouling of the membrane. However, new construction techniques, such as using asymmetric pore structures, have all but eliminated this problem. The second problem is gel polarization. This can be circumvented by the use of stirring, or crossflow, on the surface of the membrane. Thin channel crossflow provides a very high shear rate, with a moderately low recirculation rate, which "cleans" the membrane surface. Thin channel crossflow has been shown to improve the flux by two to twenty times over stirring.

Industrial Applications of Ultrafiltration:

In determining whether ultrafiltration is suitable for a process, the major factors in the decision will be effectiveness and profitability. The key cost parameters in an ultrafiltration operation are membrane cost, flux rate, and life.[9]

Electropainting process:

The first economically feasible application of ultrafiltration was in the electropainting process. The three uses of ultrafiltration were to remove excess solubilizing agents and foreign ions from the bath, recover the paint pigment, and eliminate pollution. The returned ultrafiltrate now accounts for ten to thirty percent of the total paint used. This huge materials savings allows payback times of one to two years on ultrafiltration systems. It is now standard practice to use ultrafiltration in all electropainting systems.[1]

Fermentation broth clarification:

Ultrafiltration is used here as the second step in a fermentation process. The first stage, in which sedimentation, filtration, or centrifuge are used, removes microbes and debris from the broth. The second step, where ultrafiltration, crystallization, or ion exchange are used, is to purify the product. The advantages of using ultrafiltration are that a low operating temperature can be used which allows heat-sensitive products to be made, there are no changes in phase thereby reducing energy requirements, and the filtrate is essentially free of suspended or colloidal solids and microorganisms. The disadvantage is that only low flux rates can be used, which require large membrane areas, which thus require large capital investments.[2]

Recovery of protein from cheese whey:

The recovery of protein from cheese whey is easily accomplished with ultrafiltration. It could not be done earlier because the whey fouled the membrane and the membrane was difficult to clean. Now, superrefractory membranes are tougher and can withstand vigorous cleaning techniques. Furthermore, new configurations such as hollow bundle fibers help reduce fouling. It is estimated that using ultrafiltration is two times cheaper than using a conventional separation technique such as gel filtration.[1]

Indigo dye recovery:

Indigo dye recovery is very desirable because of the high demand for the dye by denim manufacturers and because of the short supply. This basic economic dilemma was solved by using ultrafiltration to recover the dye from the rinse waters. The payback time for such a process was estimated to be 3.8 years.

Pharmaceutical and biological separations:

Ultrafiltration can be utilized in pharmaceutical and biological situations to yield ultrapure, ultraconcentrated products. Examples of the biological macromolecules separated are vaccines, peptide hormones, and plasma proteins. Pharmaceutical separations using ultrafiltration are extremely attractive from an economic standpoint because the yield is a high-value product. The improvement in the product yield, quality, or purity when using ultrafiltration relative to other processes makes ultrafiltration the only feasible choice.[9]

Other applications:

There are many processes that have only been developed recently. The test of time will tell if they are economically feasible or not. The desire for ultrapure water for the electronics, medical, and pharmaceutical industries led to new uses for ultrafiltration. Artificial kidneys are on the verge of commercialization because of the ultrafiltration techniques being used; ultrafiltration is better at removing toxic metabolic wastes than conventional hemodialyzers. Other processes that are using ultrafiltration are latex recovery, polyvinyl alcohol recovery, and oil-water separations.[13]

In the future, ultrafiltration is expected to be used in immunochemistry, hydrometallurgy, culture of mammalian cells by suing asymmetric hollow-fiber bundle membranes, and in the manufacturing of the artificial pancreas and/or liver.[13]

Conclusions:

Ultrafiltration is not "new" anymore. It has proven itself to be an invaluable and useful process, and should be regarded as an "unit operation" in every sense of the word. With continued research into new membranes and gel polarization control techniques, ultrafiltration is destined to become even more widely used in the chemical process industry.

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Deborah A. Baum is a senior in chemical engineering from Pennsville, New Jersey. Deborah is involved in many student groups including American Institute of Chemical Engineers, Tau Beta Pi, and the Student Engineers' Council. Currently, Deborah is going on plant trips, but she is also considering the possibility of going to graduate school.

Principles of Electromagnetic Shielding

by Ellen L. McGaughy

Introduction

This paper describes electromagnetic shielding theory and how the theory applies to different kinds of electromagnetic shields. The theory is based on Maxwell's equations which describe how the electric and magnetic fields flow through mediums. The equations describe field flow in terms of the material properties of the medium, and the geometric shape of the shield.

For example, Maxwell's equations predict that the electromagnetic field of a wire current circles the wire. Thus, cylinders make good shields for wires. The equations also predict that field strength decreases as the distance from a conductor increases. Thus, moving the two systems apart reduces electromagnetic interference.

The shield designer selects the shield material for the type of field he wants to shield, and the shape of shield depending on the way the field flows. This paper further describes the principles on which the designer must base his design.

Principles of Electromagnetic Shielding

People face electromagnetic interference (EMI) problems everyday. Static drowns out the music from a car radio when the car passes power lines. A thunder storm interferes with television reception. A citizen's band radio cackles with noise from other users.

EMI exists when one circuit creates fields that prevent another circuit from working well. Electromagnetic compatibility (EMC) exists when the electromagnetic (EM) fields produced by the circuits do not interfere with each other.

Designers cannot prevent all EMI from reaching a circuit. They can only reduce the EMI to levels that let the other circuit work well. Physically separating the two systems reduces EMI. When there is not enough room to separate the systems, EM shielding can protect the other system.

EM shielding works like a shield used in battle. Ancient soldiers used battle shields to protect themselves from arrows; arrows pierced the shield and stopped before wounding the soldier. The shield also reflected arrows; arrows bounced off the shield and away from the soldier.

Likewise, an EM shield absorbs part of the EM wave that strikes it, or the EM shield reflects part of the wave. The EM shield has an advantage over a battle shield. A battle shield only reflected arrows when they struck the first surface between the air and shield. An EM shield reflects at this first surface and at the second surface where the wave leaves the shield (fig. 1).

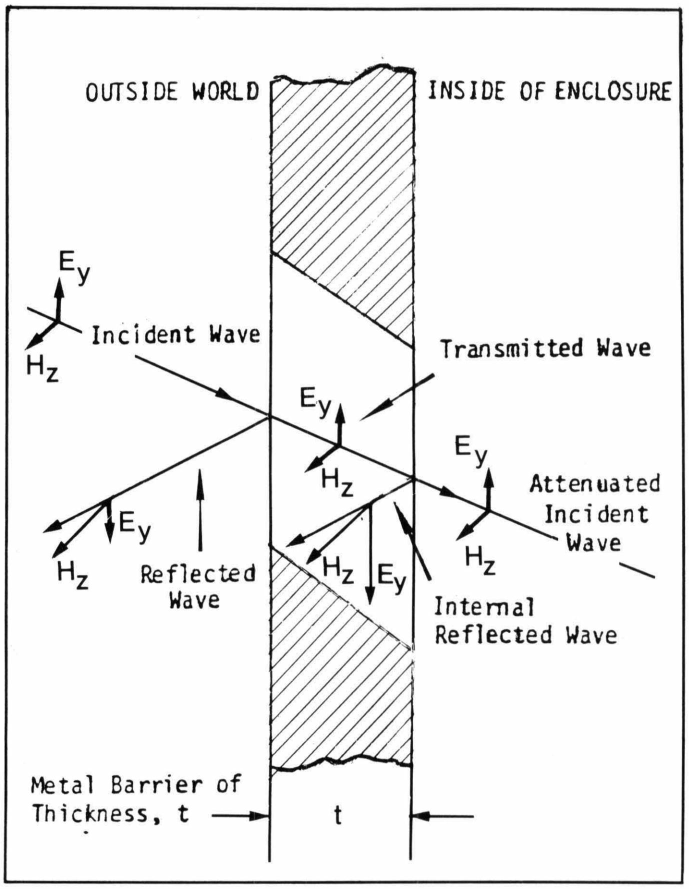

Fig. 1 Representation of Shielding Phenomena for Plane Waves[1]

The ratio of the EM field strength with the shield, to the EM field strength without the shield describes the shielding effectiveness, S. Equation (1) defines S in decibels.

$$(5)\quad S = 20\log\frac{\text{EM field strength with shield}}{\text{EM field strength without shield}}\quad \text{(dB)}$$

The sum of four terms (equation 2) gives the value for S. Each term accounts for part of the total shielding effectiveness.

$$(2)\quad S = A + R + B + K$$

where

S = the total amount of shielding,

A = the shielding due to absorption,

R = the shielding due to reflection at the first surface,

B = the shielding due to reflection at the second surface,

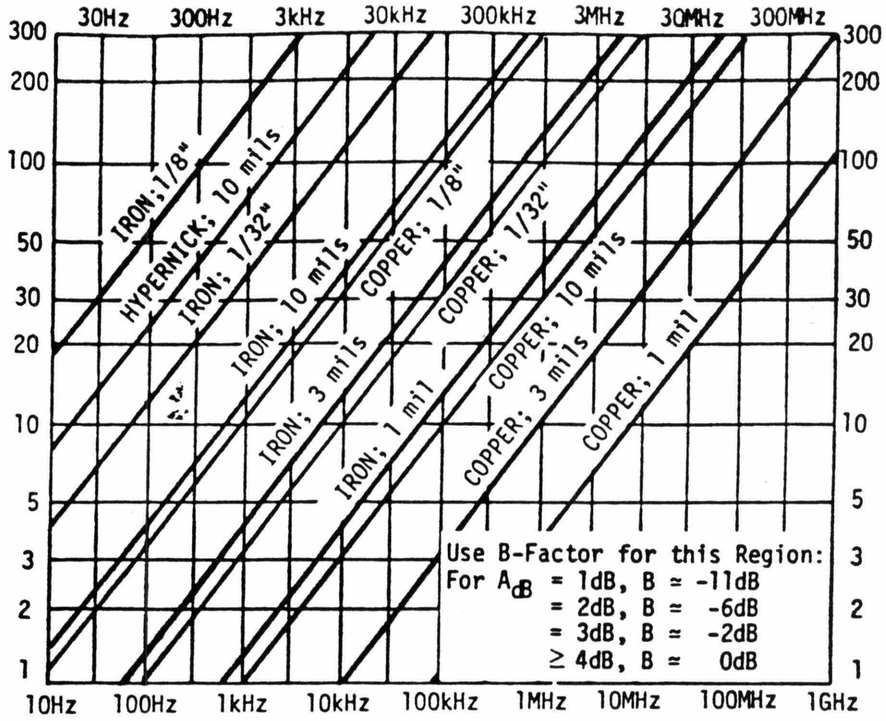

Fig. 2 Absorption Loss in dB[2]

Shielded Thickness	1050 Å		12,500 Å		21960 Å		219,600 Å	
Frequency	1 MHz	1 GHz	1MHz	1 GHz	1 MHz	1 GHz	1 MHz	1 GHz
Absorption Loss, A	0.014	0.44	0.16	5.2	0.29	9.2	2.9	92
Single Reflection Loss, R	109	79	109	79	109	79	109	79
Multiple Reflection Correction Term, B	-47	-17	-26	-0.6	-21	0.6	-3.5	0
Shielding Effectiveness, S	62	62	83	84	88	90	108	171

Table 1: Calculated Shielding Effectiveness of Copper Thin-Films[3]

K = losses in shielding due to the shield's geometry.

The impedance, η , allows calculation of the values of A, R, and B. When EM waves travel through a material, the material properties cause losses which attenuate the wave. These losses are called the absorption losses, A. The skin depth, d, is the distance into the shield where the material has attenuated the wave to a strength of e^{-1}. Thus, by the time the wave reaches the skin depth, the material attenuates most of the wave. Equation (3) defines the skin depth. η is a complex number. α is its real component.

(3) $d = 1/\alpha$

Equation (4) defines the attenuation, A, in decibels.

(4) $A = 8.69e^{-\alpha z}(\mathrm{dB})$

Thus, most of the attenuation occurs between the surface (z = 0), and the skin depth (z = d). Figure 2 graphs A for different materials.

Reflection, R, occurs when a mismatch between the materials at the shield surface exists. The ratio of the original impedance, $\eta 1$, to the impedance of the shield material, $\eta 2$, describes the degree of mismatch. If $\eta 1/\eta 2$ is less than one or exceeds one, a mismatch exists and reflection occurs. If $\eta 1/\eta 2$ equals one, the impedances are the same, and no reflection occurs. The closer the ratio is to one, the less reflection occurs.

B, the shielding due to reflection at the second shield surface, can be neglected if A exceeds 10dB. When A is 10dB, the shield is thicker than d. The shield absorbs most of the wave before it reaches the second surface. Thus, B is very small compared to S. Table 1 show values of A, R, B, and S in decibels for copper thin-films at different frequencies.

The shields discussed in this paper have simple shapes. K accounts for shielding losses due to complex shapes. Complex shields have large negative K's.

The wave impedance, η , gives values for A, R, and B, of a wave that travels through a medium. Equation (5) defines η for a wave that travels in the +z direction. For this wave, Ex is the electric field strength, and Hy is the magnetic field strength.

(5) $\eta = Ex/Hy = \frac{j\omega\mu}{\gamma}$ where and are material properties.

Since η decreases with frequency, low frequency magnetic fields are hardest to shield. In this case, η for most metals approaches η_0 of free space. Only a small mismatch exists, so little reflection occurs. Absorption must do most of the shielding. However, most materials also have large d's at low frequencies, so the shield must be very thick to shield well. Magnetic materials such as mumetal, co-netic, and iron have very small d's. Therefore, they provide better shielding with less material than non-magnetic material.

Sonar systems cabinets need magnetic shielding. The cabinets receive EMI from components such as transformers and chokes. Shield cans often protect these cabinets. Moser tested how well cans of different metals shielded at very low frequencies. His tests showed that thick cans shield better than thin cans, as theory predicts. Of the metals tested, mumetal and co-netic shielded best over the widest frequency range because of their material properties.[4]

Electric fields are easier to shield than magnetic fields. Electric field shields use conducting materials. This makes $\eta 1/\eta 2$ large, especially at the high frequencies where most EMI occurs. Thus, R is very large so most of the wave reflects. The shield does not need to absorb. This and small d's permit using thin shields. Electric field shields also work well for high frequency magnetic fields.

For example, transmission lines need to be shielded. The currents they carry create fields which interfere with other systems. Also, fields from other systems can induce unwanted voltages in the lines. Coaxial cable shields transmission lines well. In coax cable, several concentric shells surround the central conductor. A dielectric material separates the shells. This creates a η mismatch at each surface, so each shell reflects. Each shell also reflects part of the wave. Summing the shielding due to each shell gives the total shielding. Two shields usually provide good shielding.[5]

Thin-film shields, shields whose thickness is less than 1/4 the wavelength, also shield electric fields. Thin-films shield well because of their huge R's at high frequencies. They are very important for radio frequency microcircuit applications. For all shields, three main factors determine the shield design - the frequency range to shield, the desired attenuation, and the application. The designer chooses the material and type of shield accordingly.

Magnetic materials best shield low frequency magnetic fields. Non-magnetic materials best shield electric fields and high frequency magnetic fields.

The application determines the type of shield. Most shields for low frequency magnetic fields must be thick, simple structures such as cylinders. Shields for electric fields vary. Cylinder tubes shield conducting wires well. Thin-films make good shields for microcircuits.

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Inflated Fabric-Reinforced Concrete Shells

by David Hernson, BCE

Thin shells constructed using inflation techniques and nonwoven polymer fabric-reinforced concrete have been proposed for use as farm shelters, bulk storge enclosures and housing. This construction method has the advantages of:

1. low material, equipment and labor costs;
2. capability of completion in a short time span by one or two persons;
3. the requirement of the specialized construction skills.

The shells utilize the inherent strength of double curvature and can be constructed on-site or prefabricated. Three shapes, round domes, rectangular perimeter domes and hyperbolic parabaloids have been built using approximately the same methods. This discussion is given as a brief introduction to the materials and construction procedure basic to any of the shells and applications.

The Composite Material

Polymer fabric-reinforced cement laminates are a new class of construction materials having commercial potential for the production of concrete in thin sections, such as for pipes, thin shell building enclosures, corregated panels and facings for sandwich panels (1-4). Composite materials consisting of ductile fibers in a brittle matrices are as yet a little researched area of material science. No predictive models are available to relate the mechanical properties of the ductile fiber-brittle matrix composite to the mechanical properties of the constituents and there is no failure criteria established for this class of materials. Though little theory is currently available on the response of these composites, emperical studies have shown promising results. Tensile tests have shown that the materials act, at least initially, as a composite. Flexural tests have shown that the polymeric fabric-reinforced cement laminates are capable of carrying the principle and shear stresses associated with transverse loadings. In fact, these composite laminates have been shown to have linear flexural stiffness moduli prior to a distinct yield load. Results of vacuum and water pressure testing on table-size models of spherical sections have indicated that strength and deflection properties of the doubly-curved laminate are better than anticipated. Finally, full sized prototypes, by the method described later, have been successfully constructed.

The basic composite consists of layers of nonwoven polyester and/or polypropylene fabrics interspersed between layers of Portland cement. Nonwoven fabrics were chosen for the following properties:

1. Nonwovens assure uniform distribution and orientation of fibers over the surface area of the laminate;
2. The continuity of nonwoven fabric reinforcement permits construction techniques not possible with chopped fiber reinforcement (1,3,5-7);

3. The uniform, closely-spaced fibers of the nonwovens appear to induce closely-spaced, uniform, fine cracking patterns in the cement matrix;

4. Nonwovens are significantly cheaper than woven fabrics of corresponding density and fiber size (5) and are approximately the same cost per volume as chopped fiber reinforcement.

Furthermore, all the fabrics are resistant to a pH of 13, typical of hydrating cement, all have pore spaces large enough to permit complete penetration of the cement, and all are commercially avail-able.

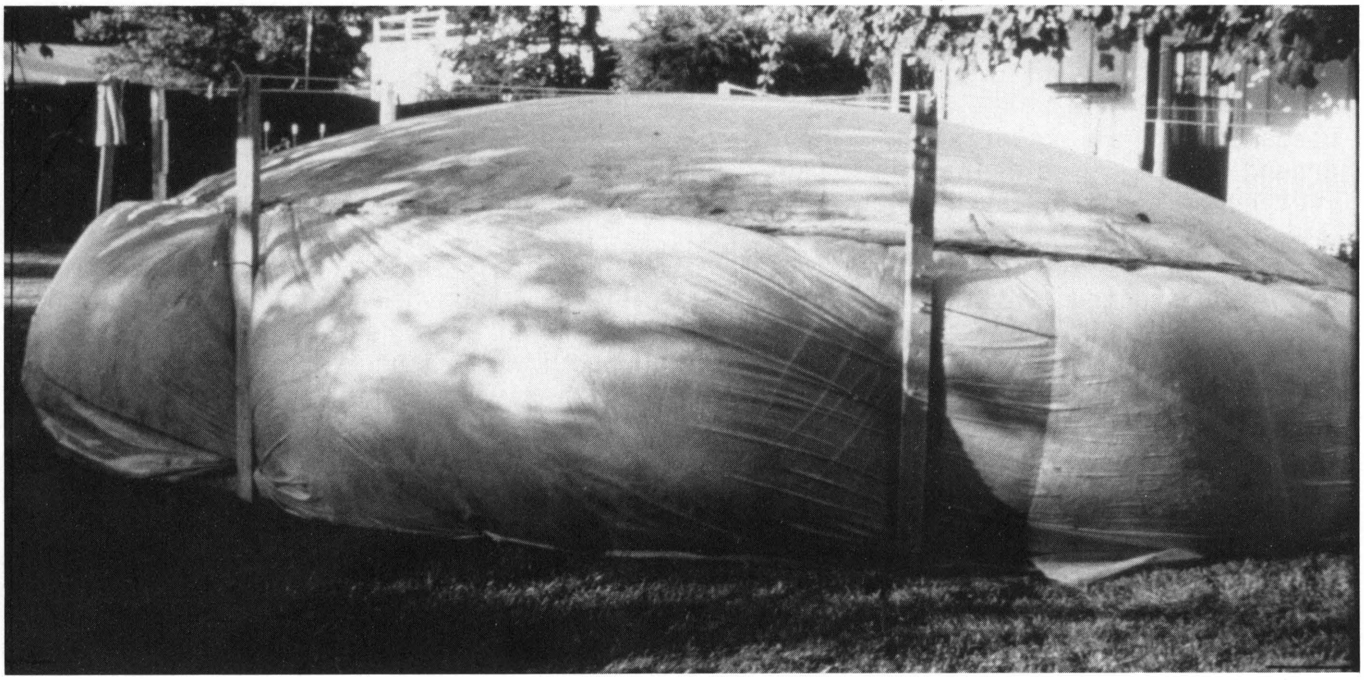
Construction Technique

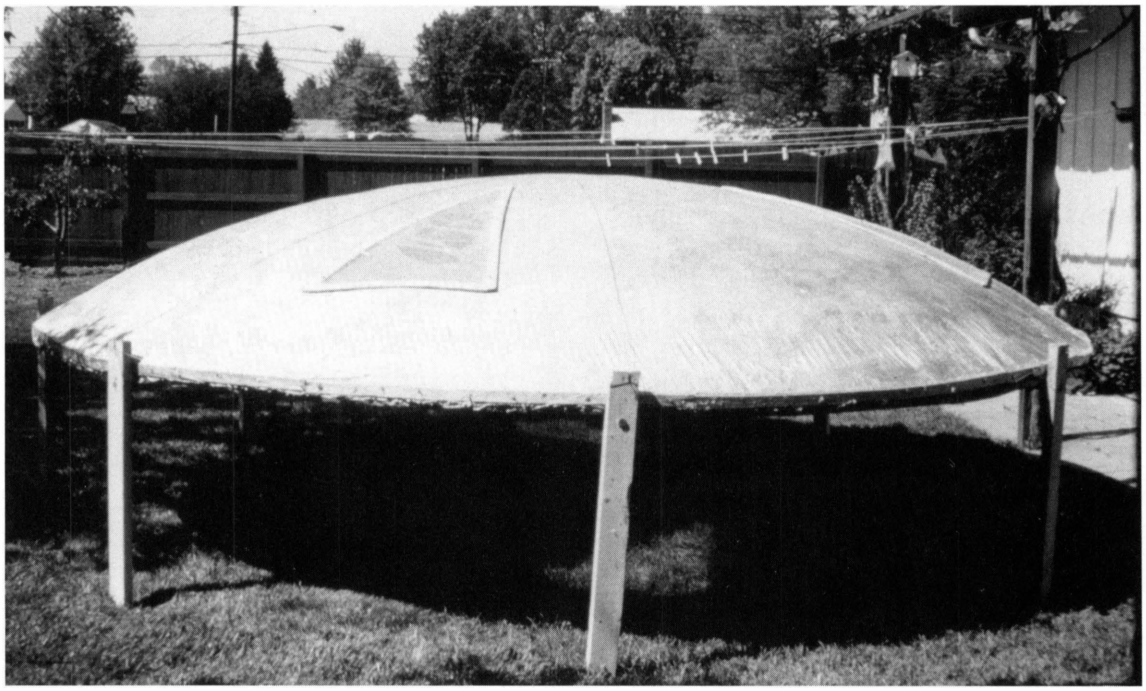
Inflated concrete shell roof structures have been built by various methods, including:

1. inflating a bag, covering it with reinforcing mesh, spraying it with concrete and removing the bag through an opening in the hardened shell for reuse (8,9);
2. inflating a bag with an airlock door, spraying the inside of the bag with insulating foam, spraying the inside of the foam with concrete, then removing the bag from the outside or leaving the bag as permanent waterproofing (10);
3. placing concrete and an expandable mesh on an elastic membrane at ground level, then inflating of concrete over the expanded surface of the resulting shell (11,12).

This paper considers an alternative method consisting of five basic steps:

1. laying a bag on the ground, connected to a corregated plastic pipe extending outside the shell perimeter in a trench;
2. spreading dry Portland cement, interbedded with layers of nonwoven fabric anchored to a rigid perimeter frame;
3. inflating the fabric-reinforced cement membrane with a ventilating blower to the desired geometry;
4. spraying with sufficient water to permit hydration of the cement.
5. when the shell has hardened adequately, removal of the blower and cutting openings for entries and skylights, or, removal of the perimeter stays and elevating the shell to set on perimeter posts using the same blower-bag apparatus.





The fabrics stretch slightly due to inflation, so that shells having round or polygonal perimeters with center rises from 1/10 to 1/5 of the span can be constructed with flat, untailored fabric. By careful tailoring of the outside fabric and overlapping inner layers, rise-span ratios of 1/3 can be obtained without appreciable loss of uniformity in shell thickness. Shell design thicknesses range form 1/300 to 1/800th of the span, depending on shell shape, design load (earth or snow cover), and distribution of supports.

Principal cost-reducing advantages of this technique over other inflated concrete shell techniques used to date include:

1. placement of all material by hand at ground level, eliminating shotcreting or guniting equipment;

2. wetting the shell after the shell has been erected and the anchorages and air seals have been pretested by inflation;

3. construction of large shells without the time constraint imposed by the period of cement hydration;

4. a minimum of necessary construction tools, including a hammer, spade, rake, and 1/3 tol Hp ventilating blower, all of which can be transported in a compact car.

The shells are typically self supporting in 24 hours, though cool weather will of course dictate longer setting times. The finish shell is fire and water resistant. Potential failure modes after removal of the inflation and loading of the shell with earth, snow, wind, or concentrated loads include:

1. Meridianal buckling due to compressive stress;

2. Perimenter elongation and cracking due to circumferential hopp stress;

3. Flexural cracking around openings, especially at corners.

Useful design references include (13,14) for spherical shells and (15) for nonspherical shells and shells with openings. The shells are so thin, even when designed for heavy earth backfill, that buckling rather than compression invariably determines thickness by a wide margin. The improvement due to fabric reinforcement at the surface rather than at mid-lane on the one hand, and the poor control of thickness on the other, limits the usefulness of available design methods. Full-scale testing, although expensive, must eventually provide the major source of design guidance.

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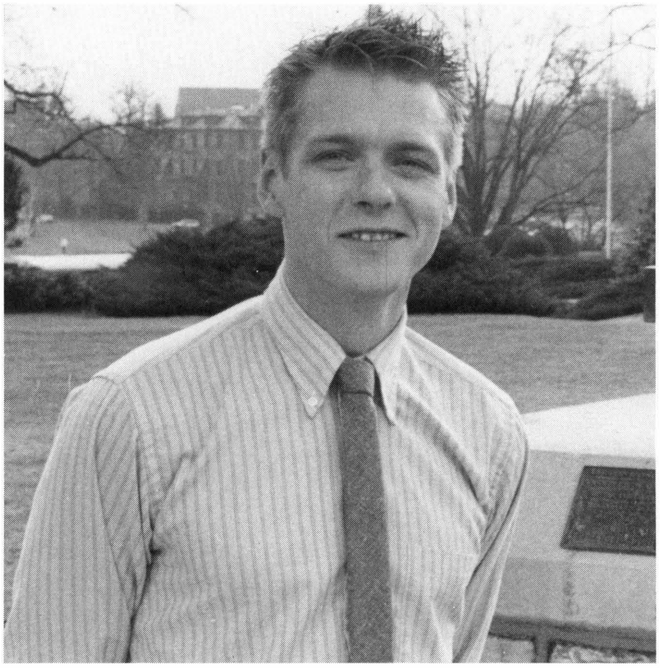

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The Effect of the Leaching Process on the Ultimate Tensile Strength of Graphite Fibers Extracted from Aluminum Ion-Plated Tapes

G. L. Childs and C. J. Skowronek

Introduction

The Naval Research Laboratory is currently investigating mechanical and physical properties of Aluminum/Graphite metal matrix composites. Low as well as high longitudinal tensile strengths of unidirectional composites have been exhibited with varying consolidation time and temperature. Since the longitudinal strength of a unidirectional composite is principally a fiber dominated property, test on single fibers were made to determine if fiber degradation is in part responsible for low longitudinal strengths measured. The tensile strength was determined for graphite fibers recovered from these composites by leaching away the aluminum matrix with hydrochloric acid[1]. An apparent strengthening of fibers above nominal original strength was observed for certain combinations of consolidation time and temperature. In this study two alternative leaching chemicals, Sodium Hydroxide (NaOH) and Hydrochloric Acid (HCl), were used to extract graphite fibers from duplicate samples of Aluminum/Graphite precursor tapes that had been subjected to thermal treatments corresponding to consolidating the tapes into plates. The effect the leaching chemical had on residual strength of graphite fibers was determined.

Experimental Procedure

A 12,000 filament tow of Celion 12,000 High Strength Graphite (PAN) fibers (Nominal 7 μm diameter) was used as the base material forthis study. Two strands of aluminum ion-plated and one strand of bare fibers were cut approximately four inches long from precursor tapes purchased from the Celanese Corporation in Chatham, New Jersey. The two samples of ion-plated fibers were placed in an oven with an argon atmosphere of 1000psi. The oven was programmed, using the oven computer, to raise and stabilize the temperature at 470°C in 10 minutes. The oven remained at this temperature for an additional 10 minutes. It was then shut off and allowed to cool to about 200°C. The pressure chamber was vented causing the temperature to decrease to about 90°C. To prevent condensation on fibers, the pressure chamber was closed and the oven turned on for another 10 seconds. Turning the oven off and venting the chamber once more caused the temperature to fall to just below 50°C. The pressure chamber was again closed and the oven turned on for another 10 seconds. Final venting reduced and temperature inside the pressure chamber so that the ion-plated fibers could be retrieved. The bare fibers were then placed in the oven and the above procedures duplicated.

ASTM standard test method (D 3171-76) for digestion of reinforced metal matrix composites was used as a guide for extraction of the fibers from the ion-plated tapes.[2] One strand was leached in a hot (80°C) 60% NaOH aqueous solution, the other in a hot (75°C) 10% of HCl solution. Complete digestion of the aluminum matrix from the graphite fibers required 30 seconds and 2 minutes 15 seconds for the NaOH and HCl solutions respectively. After leaching, the reaction solutions were poured off and each sample was washed twice, first in acetone then in distilled water. The fibers were placed in an oven at 75°C to dry. Each fiber strand was then tested for strength by mounting a single fiber, secured with Duco cement, across the diameter of a one inch hole in a 3x5 index card. A sample size of 40 fibers was used for each strand. After installing the card in the grips of an Instron tensile testing machine, the card was severed in the gage section by burning through with a hot wire. Each fiber was then loaded to failure at a strain rate of 10^{14} sec^{-1}. The frequency distributions of breaking loads for each sample population of fibers resembled a "normal" population density. The Central Limit Theorem, which gives a value of a random variable whose distribution function approaches that of a normal distribution when the sample mean and variance are given, was used to determine if the leaching process had an effect on the ultimate tensile strength of graphite fibers extracted from aluminum ion-plated tapes. Fibers selected from each strand were examined further with a Scanning Electron Microscope (SEM) including an Energy Dispersive Spectrometer (EDS). Data is presented in histograms showing the breaking load frequency for the bare Celion fibers, NaOH and HCl extracted fibers in Figures 1A, 1B, and 1C respectively.

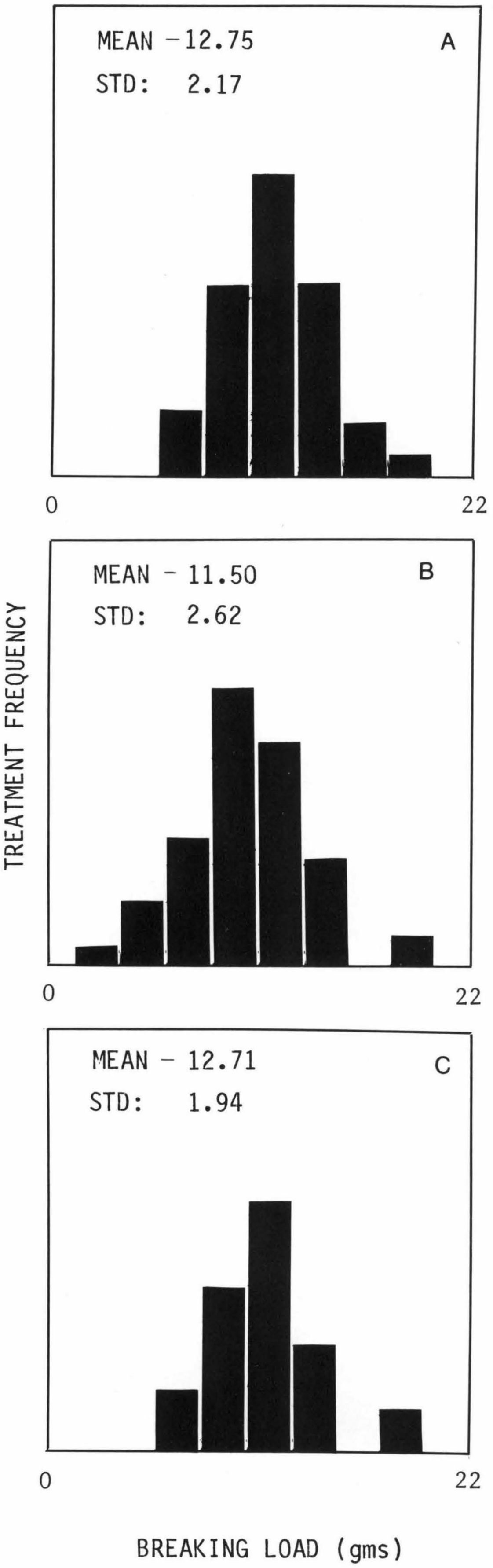
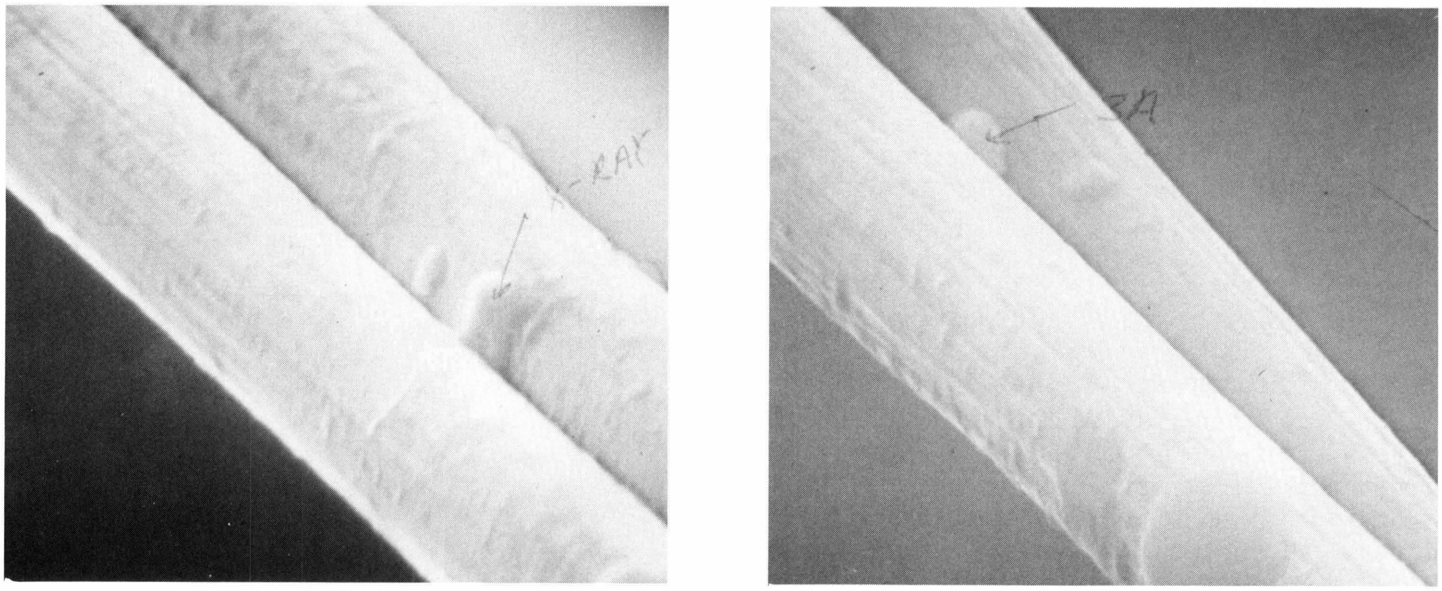


Figure 1: Frequency vs. breaking load histograms for fibers subjected to thermal treatment (470° C) and argon pressure (1000 psi) of (a) bare fibers, (b) ion-plated fibers leached in sodium hydroxide, and (c) ion-plated fibers leached in hydrochloric acid.

Discussion

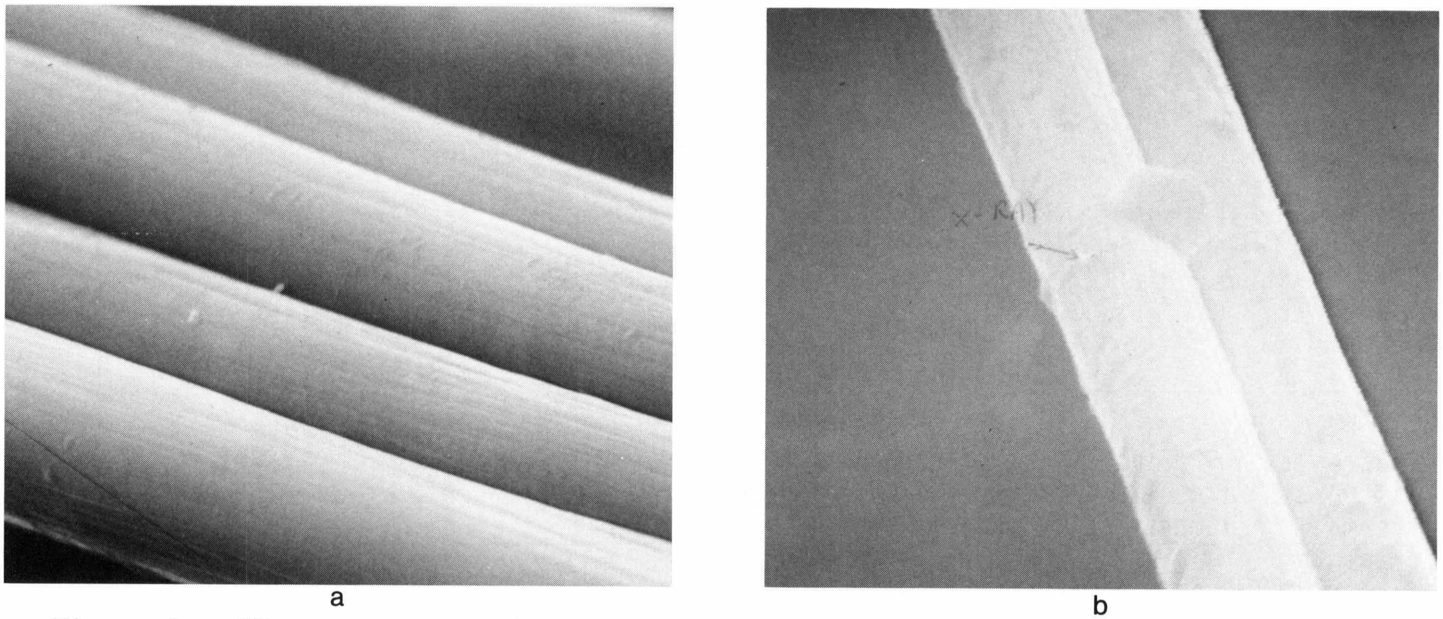
SEM and EDS studies showed several points of interest. The surface appearance of all fiber samples, shown in Figures 2 and 3, are very similar. Nodules observed on each heat treated fiber sample did not contain measurable quantities of elements with an atomic number of thirteen or greater. Since the nodules were not seen on the as-received fibers, they may consist of anomalous carbon formations which developed or grew during the fiber heat treatment. Figure 4 shows EDS data for each of the fiber surface samples. There were no significant amounts of aluminum on any of the fibers. This indicated that the leaching chemicals and procedures were sufficient to completely digest the aluminum from the ion-plated precursor tapes. The two peaks to the far right of each figure were copper and zinc respectively. Both peaks were attributed to the brass specimen holder.



a

b

Figure 2: Fiber surface of ion-plated fibers after extraction in (a) Hydrochloric acid and (b) sodium hydroxide.
Surface appearance of Celion bare fibers as received and subjected to thermal treatment



a

b

Figure 3: Fiber surface of (a) bare as received fibers and (b) fibers subjected to thermal treatment (470 C)

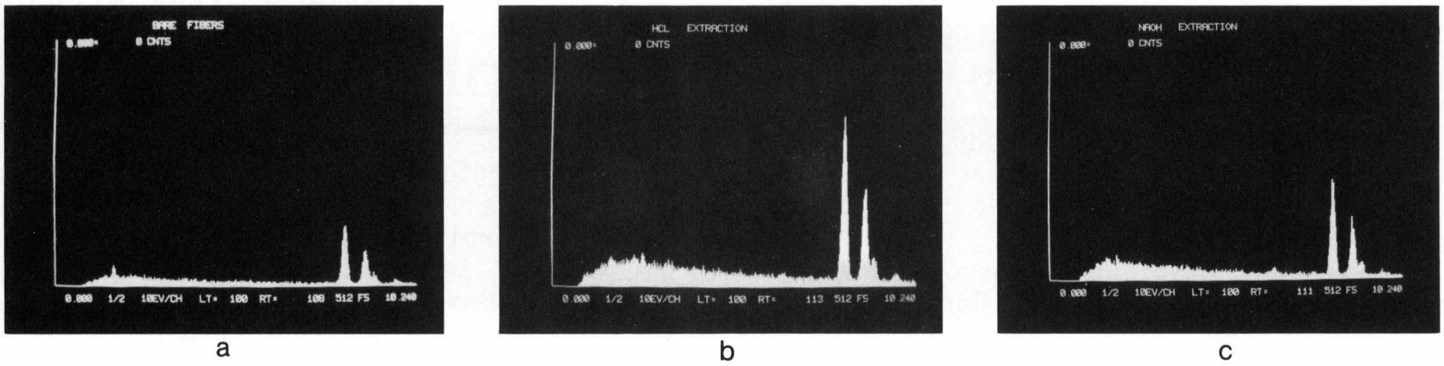


Figure 4: X-ray elemental analyses of (a) bare fibers, (b) fibers leached in HC , and (c) fibers leached in NaOH.

A summary of the results from tensile tsts on bare and extracted fibers is presented in Table 1. There was no significant change in the average breaking load of either the bare fibers after heat treatment or the ion-plated fibers after leaching in HCl. However, the breaking load distribution of the fibers leached in NaOH exhibited a lower mean and higher standard deviation than the other two fiber populations indicating fiber degradation had occurred. Using the Central Limit Theorem, the NaOH extracted fibers were statistically different from the bare fibers and fibers leached in HCl.

Conclusion

The leaching process affects the ultimate tensile strength of graphite fibers extracted from aluminum ion-plated tapes. Bare heat treated fibers showed no difference in surface appearance from fibers leached in HCl or NaOH. Therefore, the reaction product of NaOH and the aluminum matrix may have caused fiber deterioration during extraction. HCl extraction, however, has no effect on fiber strength.

	Mean Breaking Load	Standard Deviation
Bare Fibers (No Heat Treatment)	12.46g*	
Bare Fibers (Heat treated)	12.75g	2.17
HCl Extracted Fibers	12.71g	1.94
NaOH Extracted Fibers	11.50g	2.62

*Manufacterer-reported value (40 individual fibers tested).

Table 1: Summary of Results from Tensile Tests on Bare and Extracted Fibers.

Acknowledgements

The authors gratefully acknowledge Messrs. Richard Everett, Lowell Humphreys, and Ms. Nancy Nutter for their assistance in this study.

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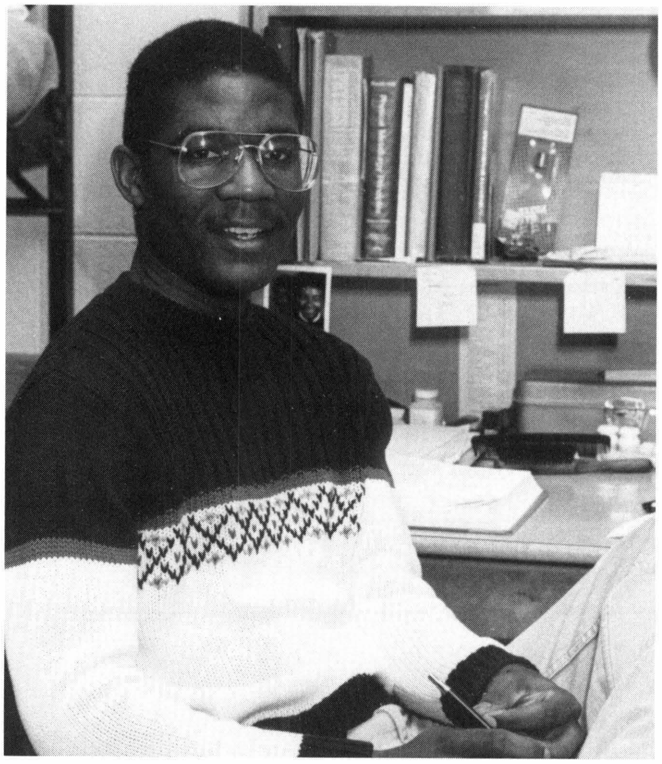

Garrett L. Childs is a junior in materials engineering from Capitol Heights, Maryland. Garrett's article is based on work that he did during his summer employment at the Naval Research Lab. This spring, Garrett will represent Virginia Tech at the American Ceramics Society's student speaking contest in Cincinnati, Ohio. Here at Tech, Garrett has enjoyed his involvements in the Resident Adviser program and the Baptist Student Union. Garrett's plans for the future include graduate work in materials engineering.

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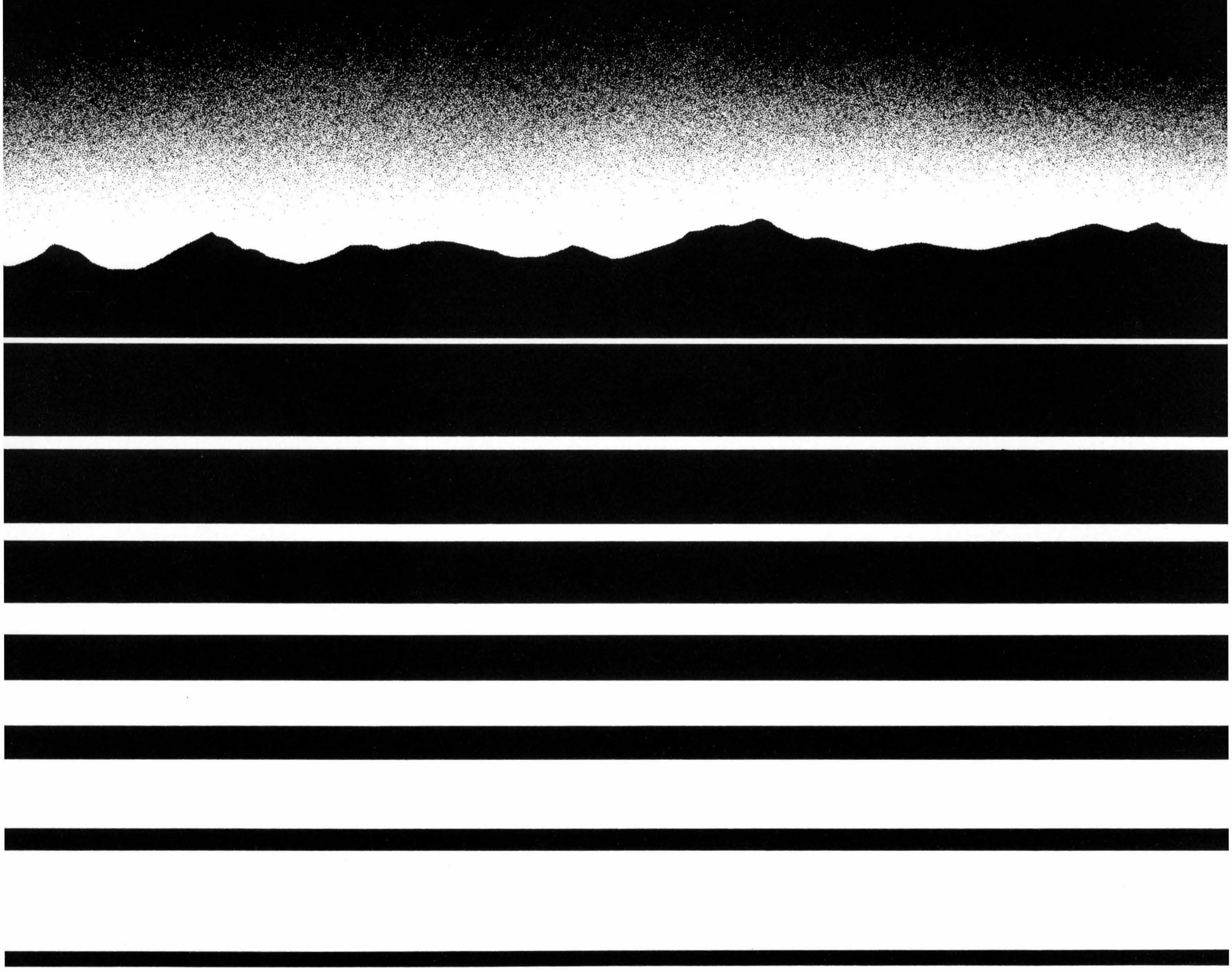

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