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INVESTIGATION OF THE KINETICS OF CRYSTALLIZATION OF SEVERAL HIGH TEMPERATURE GLASS SYSTEMS

J910939-3

by
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SEPTEMBER 1, 1970

United Aircraft Research Laboratories
UNITED AIRCRAFT CORPORATION
EAST HARTFORD, CONNECTICUT

QUARTERLY STATUS REPORT NO. 3

CONTRACT NASW-2013

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Report J910939-3

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DATE 9/1/70

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Investigation of the Kinetics of Crystallization of Several High Temperature Glass Systems

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SUMMARY

Research designed to measure the possible usefulness of the UARL 344 glass composition has proven that fibers can be readily and continuously drawn from this composition through a multihole (six hole) platinum-rhodium bushing at high rates of speed. Further, the process operating variables can be so adjusted that the glass fibers can be started through the use of simple mechanical devices without any help from the operator. It should now be possible, therefore, to prepare any samples needed by external agencies for a fuller evaluation of UARL 344 glass fibers without undue costs.

Composites made with UARL 344 glass fiber and epoxy have shown full-size notched Charpy impact test values of 30 foot pounds or about three times the value of comparable tests on boron fiber-epoxy composites and more than seven times as high as obtained with graphite fiber-epoxy resin composites tested similarly.

Twenty new non-toxic (beryllia-free) glass compositions were prepared in this quarter. About half of these have been examined in bulk form and the best of those so far measured are UARL 454 with a Young's modulus of 18.93 million psi and a specific modulus of 145 million inches, and UARL 447 with comparable values of 18.23 million psi and a specific modulus of 154 million inches.

Preliminary studies of the mode of fracture of the new UARL glass compositions are underway and electron micrographs are included in this report to illustrate the striking contrast between the fracture surfaces for a material such as Corning Glass Works 9608 Pyroceram* and UARL 344 glass. Full-size unnotched Izod impact values for the 9608 are 1.8 foot pounds and for the UARL 344, 4.0 foot pounds respectively. Comparative studies of several UARL glasses and a borosilicate sight glass carried out on half-size notched Charpy impact specimens are also included in this report.

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*Corning's trademark for its crystalline materials made from glass

INTRODUCTION

The present report is the third quarterly report for the new contract between UARL and NASA Headquarters, i.e. NASW-2013 entitled "Investigation of the Kinetics of Crystallization of Several High Temperature Glass Systems". The research follows directly from the former contract, NASW-1301, "Investigation of the Kinetics of Crystallization of Molten Binary and Ternary Oxide Systems" under which sixteen quarterly reports were issued. The new contract differs from the earlier contract in the major emphasis placed on the selection of those two compositions offering the most potential as sources for glass fibers with outstanding properties. Further, it is expected under the new contract that some of the research will include an investigation of those problems that arise when an effort is made to produce large quantities of the two selected fibers and in manufacturing glass fiber-resin composites and an extensive study of any properties of these fibers or composites not previously investigated.

The first part of both the second quarter's report and of this report consists, therefore, of applied research considerations such as the changes in single hole bushing design and the successful use of the multihole or six hole platinum-rhodium bushing to produce more than eighty million lineal feet of fiber from one selected glass composition, namely UARL 344. This portion of the report also includes data obtained when this eighty million feet of fiber from UARL 344 is incorporated into glass fiber-resin composites together with all other measured properties of this particular fiber including an assessment of its strength. It also includes that part of the research when the composition of the UARL 344 beryllia containing glass is altered in an effort to further improve its working characteristics.

The second half of this report, however, is given over to the basic research underway in an attempt to produce a second but nonberyllia containing glass composition equal or superior in properties to the UARL beryllia containing glass. It will be noted from the tabulated data of the report that considerable progress has been made in this respect but that this goal is not completely achieved as yet. The results of measurements of the properties of the new glass compositions are also contained in this section of the report.

RESEARCH CONCERNED PRIMARILY WITH FIBERS FROM UARL 344 GLASS

Multihole (6-hole) Bushing Operations

In this period the first attempts to draw fibers from UARL 344 glass composition through the use of a multihole bushing were made. Figure 1 shows a photograph of the six-hole bushing actually used. Figure 2 shows six glass fibers being drawn simultaneously from this bushing. Although several large-scale glass fiber manufacturers indicated that they did not think multihole operations with the UARL 344 glass composition would be feasible, actually UARL

UARL DESIGN 6-HOLE PLATINUM-RHODIUM BUSHING

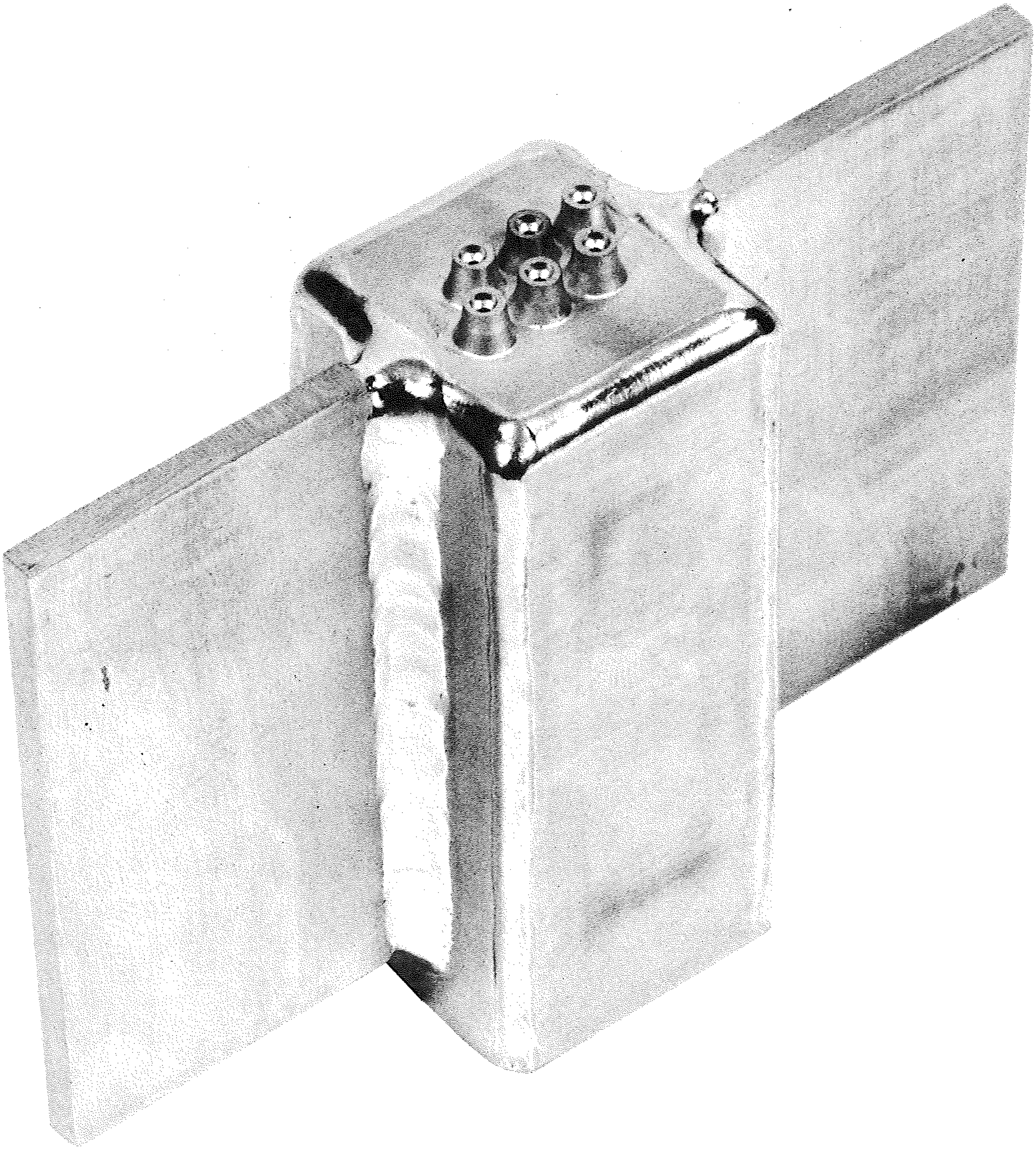
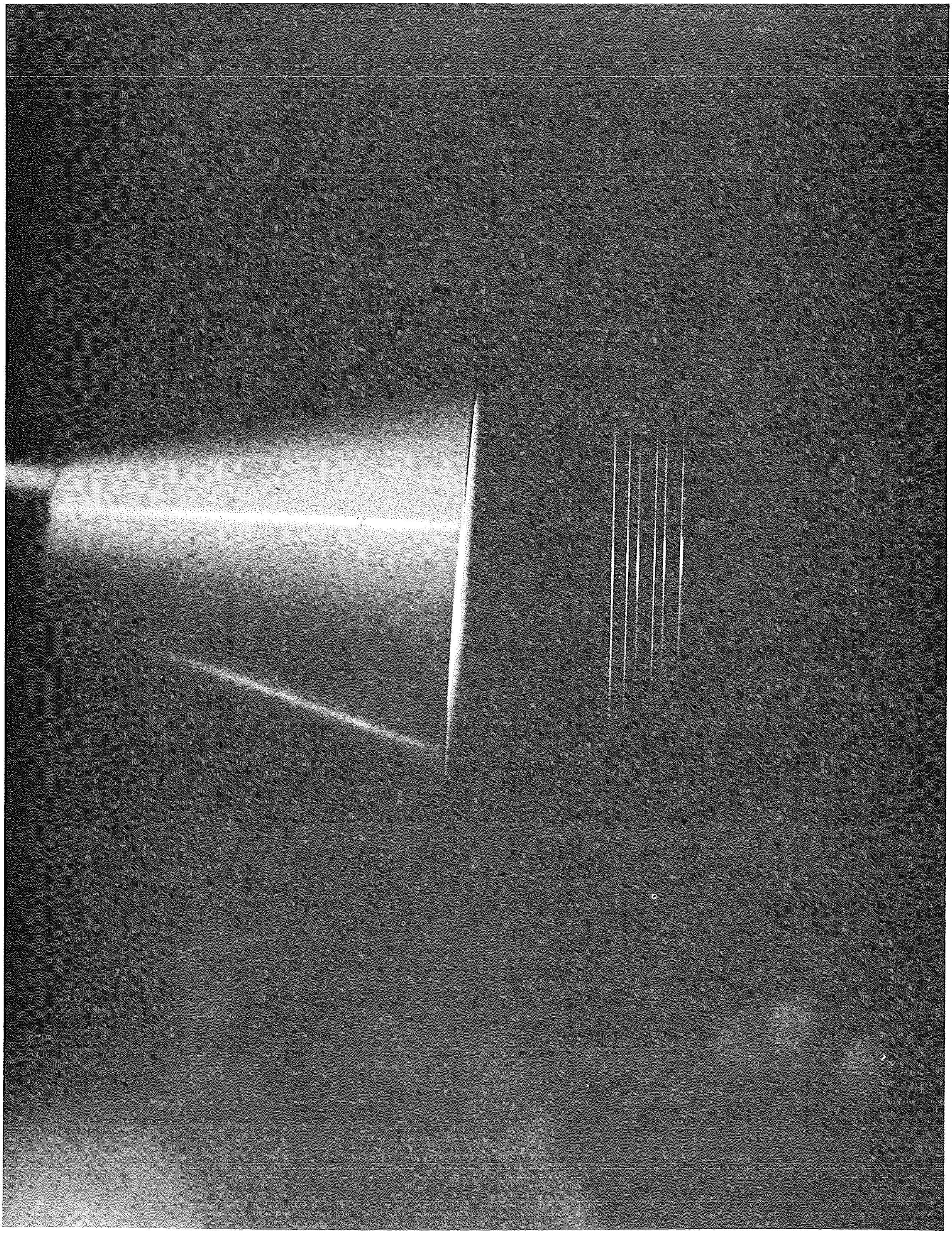


FIG. 2

6 UARL 344 GLASS FIBERS ARE SIMULTANEOUSLY DRAWN FROM EXPERIMENTAL 6-HOLE BUSHING



has found no problem in drawing fibers from the six-hole platinum-rhodium bushing. A typical temperature profile for the bushing during successful six-hole operation is a reading of 1315 to 1360°C for the thermocouple on the edge of the bottom weld and 1480°C for the thermocouple an inch and a quarter up from the bottom weld and on the opposite side. Hole size for this bushing is 0.038 in. diameter in marked contrast to the much larger hole size employed in most commercial bushings. The holes are placed on quarter-inch centers in two rows. Drawing speeds for successful operation have so far been in the range of 3000 ft/min to 6000 ft/min. Original trials using a water-ring cooler of the type employed in our monofilament operations showed the necessity of using alternate cooling schemes. Replacement of the water-ring with a system of small air jets for cooling proved to be satisfactory. More recently a simplified version of the air jet system comprised of only two air jets seems to be even better.

No composite samples have as yet been fabricated from UARL 344 glass fiber using the 6-hole bushing and no measurements have as yet been made on the fiber itself. Therefore, the effects of multihole operation on the properties of this glass are completely unknown at this time.

Typical UARL 344 Glass Fiber-Epoxy Resin Composites

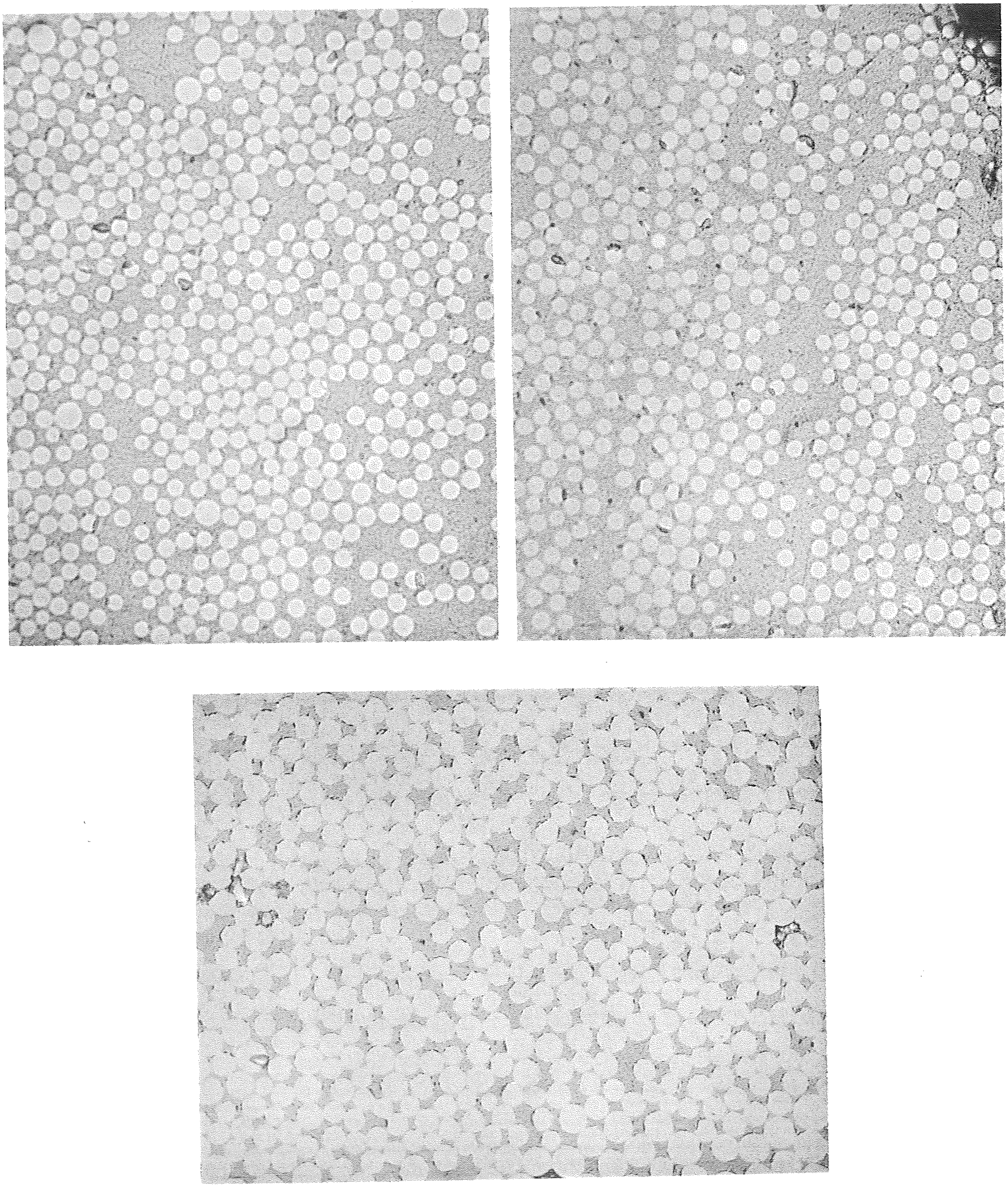
Micrographs of three UARL 344 glass fiber-epoxy resin composites recently prepared in our laboratory are shown in Fig. 3. While we can not claim that these composites are as uniformly filled as similar commercial composites, it should be noted that there is virtually no glass-to-glass contact, that variation in glass size is relatively small, and that all the glass fibers are at least as round as the very best grades of tungsten or stainless steel or copper wires. It is believed, accordingly, that measurements made on these and similar composites give a valid picture of the properties of such composites.

Comparative Evaluation of UARL 344 Glass Fiber-Epoxy Resin Impact Specimens

Full-size notched Charpy specimens were prepared from graphite fiber-epoxy resin, UARL boron fiber-epoxy resin, UARL 344 fiber glass-epoxy resin, and fully sized Owens-Corning "S" fiber glass-epoxy resin and subjected to impact in an impact testing machine. The results of the test are shown in Table I. It will be noted that the UARL 344 glass-epoxy resin composite has a value greater than seven times that of graphite fiber-epoxy resin and three times that of boron fiber-epoxy resin. However, apparently the higher modulus of UARL 344 glass compared to Owens-Corning "S" results in a lower impact value for UARL 344 glass fiber composite at least in this case where unsized and unprotected UARL 344 glass fiber was incorporated in the composite in contrast to fully sized and protected "S" glass roving. The test, of course, will be repeated using sized specimens of UARL 344 glass fiber.

FIG. 3

UARL 344 FIBER GLASS-EPOXY RESIN COMPOSITES



500X ENLARGEMENT

Table I

Preliminary Data on Comparative Impact Tests of Some of the Newer Fiber-Epoxy Resin Composites

Type of Sample	% Fiber	Impact Value (ft lbs) Full Size Notched Charpy	Young's Modulus Millions psi
Graphite Fiber-Epoxy	55	4	50
Boron Fiber-Epoxy	55	10	58.5
UARL 344 Glass-Epoxy	63.3	30	18.6
Owens-Corning "S" Glass-Epoxy	65	54	12.4

The machine used for these tests is the Tinius Olsen Testing Machine Company's "Model 64 Universal Impact Testing Machine". The hammer weighing 60 pounds undergoes a 4.4 foot drop and strikes the specimen with a velocity of 16.8 feet per second and an energy of 264 foot pounds.

The values for the fiber glass-epoxy resin composites suggests that spar propellers, for example, should be made with 3 layers of boron fiber and one of glass fiber for optimum impact resistance to form a composite-composite.

PROGRESS ON NEWER GLASS COMPOSITIONS

New Glass Compositions Prepared in Third Quarter

Those new glass compositions prepared in this quarter are shown in Table II in terms of actual grams of ingredient. It will be noted that all of these new glasses are beryllium-free. The compositional guidelines used in preparing these glasses are emphasized in Table III where some of the same glasses as those shown in Table II are entered. Here their composition is expressed in mol percent, their modulus, specific modulus, and fiberization characteristics are also given if they have been measured prior to the writing of this report.

None of the new glasses listed in Table III attain as high a value for Young's modulus as UARL 383 glass composition which has a value for Young's modulus measured on bulk specimens of 22.75 million psi. However, all of them are better glasses in the sense that they show longer working ranges and in general form glasses more readily and this is the direction we are currently emphasizing. It will be noted that the two best, UARL 447 and UARL 454, have about the same modulus (18.23 million psi vs 18.93 million psi) although one has 38 mol % silica and the other has 25 mol % silica and 13 mol % boric oxide.

Moduli of Some of the Newer Glasses In Bulk Form

The values for Young's modulus measured on bulk specimens of glass are brought up to date in Table IV. As is usual, these values are measured by our improved ultrasonic technique described in earlier reports. The modulus values for glasses UARL 433 through 440 had been reported in our last report and it will be noticed that the values now listed for these glasses are not the same but are approximately 900,000 psi higher. This happened because starting with glass UARL 433 we calculated the modulus using a computer program. This computer program assumed a Poissons ratio of 1/6 but subsequent experimentation shows that the Poisson ratios for our glasses are more usually in the range of 1/4 to 0.27. All earlier glasses had been hand calculated and so their values remain unchanged.

Table II

New Glass Compositions
Actual Ingredients in Grams

Actual Ingredient	447	448	449	450	451	452	453	454	455	456
Silica (SiO_2)	98.0	97.1	97.5	94.4	155.8	151.2	153.6	148.4	116.8	114.3
Alumina (Al_2O_3)	---	---	---	38.4	---	---	---	38.1	---	---
Lithium Carbonate	49.5	33.4	33.6	32.3	48.3	46.8	31.4	30.3	86.1	84.2
Calcium Carbonate	97.9	97.0	97.5	56.4	97.0	95.3	96.5	56.1	116.8	114.0
Zinc Carbonate	81.7	64.9	32.7	31.6	82.1	63.6	32.6	31.3	146.0	144.5
Magnesia (MgO)	40.0	39.1	52.4	50.6	39.5	38.4	53.7	50.7	47.0	30.7
Fused Boric Acid	105.0	103.8	104.2	100.8	---	---	---	---	96.2	142.0
Copper Oxide	---	10.3	10.3	10.0	---	10.1	13.0	12.6	---	---
Titanium Oxide(not rutile)	---	10.35	15.6	15.2	---	15.2	19.6	18.9	---	---
Yttrium Oxalate	473	468	470	457	473	472	467	451	234.6	228.7

	457	458	459	460	461	462	463	464	465	466
Silica (SiO_2)	115.3	113.5	103.4	101.9	118.7	100.9	101.4	117.3	97.5	123.9
Magnesia (MgO)	46.4	45.6	41.6	35.5	41.4	32.45	31.65	47.2	36.6	50.0
Lithium Carbonate	84.9	55.7	71.0	64.8	75.7	107.0	64.5	86.5	66.9	91.6
Calcium Carbonate	76.8	113.3	96.1	87.9	102.6	87.2	88.0	117.2	90.8	124.2
Zinc Carbonate	143.8	141.8	120.8	110.3	128.7	100.8	110.3	100.8	103.7	156.0
Fused Boric Acid	141.5	140.2	67.9	109.2	127.0	99.4	100.0	144.7	120.1	127.5
Zirconium Acetate	---	---	---	---	257.5	---	---	---	---	---
Yttrium Oxalate	230.5	227.2	414.5	408.0	---	406.0	407.0	235.5	390.5	124.9
Titanium Oxide(not rutile)	---	---	---	---	---	21.5	10.8	---	---	---

Table III

Compositional Guideposts for the Development of Nontoxic (no BeO) Improved High Modulus Glasses

Compositions in Mol Percent													Bulk Properties			
Glass	SiO$_2$	Al$_2$O$_3$	MgO	Li$_2$O	CaO	ZnO	La$_2$O$_3$	Ce$_2$O$_3$	B$_2$O$_3$	ZrO$_2$	Y$_2$O$_3$	^{a}CuO ^{b}TiO$_2$	Young's Mod. 10^{6}psi	Spec. Mod. 10^{7}in.	Fiber Mod. 10^{6}psi	Molar Sum
125	41.66	25	18.33							10			16.1	161		70.1
126^{xyz}													16.8	134	16.15	83.0
127^{xy}	60	10	20								10		16.1	137	15.2	79.2
129^{xy}	50	13.33	26.66								10		16.5	138	16.7	77.8
237^{x}	45	15	30								10		17.91	150		77.0
270	25	8	15	15	15	15					7		20.25	159		70.13
290^{xyz}	25	8	15	15		15			15		7		14.5	123	14.3	72.2
291^{xyz}	25	12	12	12		12			15		12		15.67	131	13.6	83.0
299^{x}	25	8	15	15			7		15	15			14.6	127	12.8	75.4
300^{xyz}	25		15	15	15	15			15				14.45	139	13.4	56.6
304^{y}	35	15	30			10					10		19.2	147		79.1
$320B3^{xy}$	45	15	30							10			16.0	151	18.6	66.7
$321A^{xy}$	40	15	30								15		18.7	142	17.4	85.3
337	30	15	30			12.5					12.5		20.9	147		83.8
363	39	12	24	6		6			6		10	$^{a}3$	19.3	149		76.3
383^{y}	24	3	16	12	12	8			10	12		$^{b}3$	22.75	200		64.9
390^{yz}	20	6	16	12	12	8			14		12		16.8	139		78.2
402^{xy}	25	8	20	5	9				14		14	$^{a}3$ $^{b}3$	17.8	148.5	16.5	83.1
403^{xy}	25	8	20	5	6				14		14	$^{a}2$ $^{b}3$	17.2	140.5	16.1	86.2
447^{y}	25		15	10	15	10			13		12		18.23	154		76.8
448^{xy}	25		15	7	15	8			13		12	$^{a}2$ $^{b}3$	16.91	133		77.4
449^{y}	25		20	6	15	4			13		12	$^{a}2$ $^{b}3$	18.08	148		77.0
450^{y}	25	6	20	6	9	4			13		12	$^{a}2$ $^{b}3$	17.78	147		79.7
451	38		15	10	15	10					12					76.5
452^{y}	38		15	7	15	8					12	$^{a}2$ $^{b}3$				78.9

Table III (Cont'd)

Compositions in Mol Percent													Bulk Properties			
Glass	SiO_2	Al_2O_3	MgO	Li_2O	CaO	ZnO	La_2O_3	Ce_2O_3	B_2O_3	ZrO_2	Y_2O_3	^{a}CuO ^{b}TiO_2	Young's Mod. 10^6psi	Spec. Mod. 10^7in.	Fiber Mod. 10^6psi	Molar Sum
453	38		20	6	15	4					12	$^a2$ $^b3$				77.7
454^y	38	6	20	6	9	4					12	$^a2$ $^b3$	18.93	145		80.5
455^y	25		15	15	15	15			10		5		15.96	135		64.4
456^y	25		10	15	15	15			15		5		15.02	130		65.9
457^y	25		15	15	10	15			15		5		15.93	139		65.1
458^y	25		15	10	15	15			15		5		15.23	132		66.4
459	25		15	14	14	14			8		10		17.34			72.6
460	25		13	13	13	13			13		10		16.83			73.6
461	25		13	13	13	13			13	10			14.80			63.4
462	25		12	12	13	12			12		10	$^b4$				74.5
463^y	25		12	13	13	13			12		10	$^b2$				74.1
464^y	25		15	15	15	10			15		5					64.1
465	25		14	14	14	8			15		10					77.1
466	25		15	15	15	15			12.5		2.5					60.5
467	25	8	15	10	15	15			5		7					
468	25	8	15	7	15	15			8		7					
469	25	8	15	5	15	15			10		7					
470	25	8	15	15	10	15			5		7					

^{x}Fiberizable
^{y}Good Quality Glass
^{z}Favorable Liquidus

Table IV

Summary Extended, All Values for Young's Modulus Measured on Circular Rods formed Directly from Melt

Glass No.	Density gms/cm^3	Density lbs/in.^{3}	Young's Modulus millions psi	Specific Modulus 10^7 in.	Difference Between Hand and Computer Calculations
433	3.6325	0.1308	19.12	14.65	0.57
434	3.5304	0.1273	19.43	15.35	0.88
435	3.4605	0.1247	20.36	16.33	0.98
436	3.4461	0.1240	19.90	16.05	0.40
437	3.5067	0.1265	19.41	15.35	0.86
438	3.2348	0.1165	18.25	15.65	0.90
439	3.3510	0.1207	19.95	16.55	0.98
440	3.3426	0.1203	19.72	16.37	0.69
441	3.2739	0.1181	19.52	16.52	0.76
442	3.5959	0.1297	20.02	15.45	0.92
443	3.6695	0.1326	20.10	15.17	0.81
444	3.5011	0.1263	19.33	15.35	0.69
445	3.4488	0.1245	17.61	14.14	0.71
446	3.5049	0.1263	20.01	15.85	1.38
447	3.2975	0.1188	18.23	15.35	1.37
448	3.5173	0.1268	16.91	13.34	0.32
449	3.3944	0.1223	18.08	14.80	0.90
450	3.3598	0.1212	17.78	14.65	0.92
451	3.5527	0.1280			
452	3.6114	0.1302			
453	3.6837	0.1327			
454	3.6142	0.1303	18.928	14.53	0.92
455	3.2860	0.1186	15.96	13.46	0.53
456	3.2099	0.1158	15.02	13.00	
457	3.1765	0.1144	15.93	13.89	1.32
458	3.2094	0.1158	15.23	13.15	0.40
459			17.34		0.80
460			16.83		0.93
461			14.80		1.04

Examination of Table IV shows that twelve of the beryllia glasses based on the much studied composition UARL 344 have moduli over nineteen million psi whereas the best recent nonberyllia glass, UARL 454, has a modulus of 18.93 million psi. However, this new UARL 454 is much more workable than the antecedent glass, UARL 270, and is a step toward catching up with the very favorable working characteristics of the beryllia glass, UARL 344.

A Preliminary Look at the Mode of Fraction on Impact of the New UARL Glasses

Full sized unnotched Izod specimens were prepared from Corning Glass Works Pyroceram 9608 and UARL 344 glass. The fractured surfaces of these two materials as photographed using scanning electron microscopy are shown in Figs. 4 and 5 for Corning's 9608 Pyroceram and in Figs. 6 and 7 for the UARL 344 glass. It will be noted that the 9608 shows the typical granulated fracture of a highly crystalline material while the UARL 344 shows numerous striations and conchoidal fractures within these striations. The transparency of the UARL 344 specimen lends a hazy appearance to the bottom of the conchoidal fracture since the deposited plating cannot completely fill the fracture. The relative Izod values for the specimens were 1.8 foot pounds for the Corning 9608 and 4.0 foot pounds for the UARL 344.

Additional impact specimens were prepared from other glasses being in this case half-sized notched Charpy impact specimens. The fractured surfaces of these specimens have not het been examined by scanning electron microscopy. The impact test data is shown in Table V. It will be noted that UARL 304 is the toughest of the specimens tested. Further, it can be seen that toughness or resistance to Charpy impact fracture cannot be correlated with Young's modulus alone in any simple fashion.

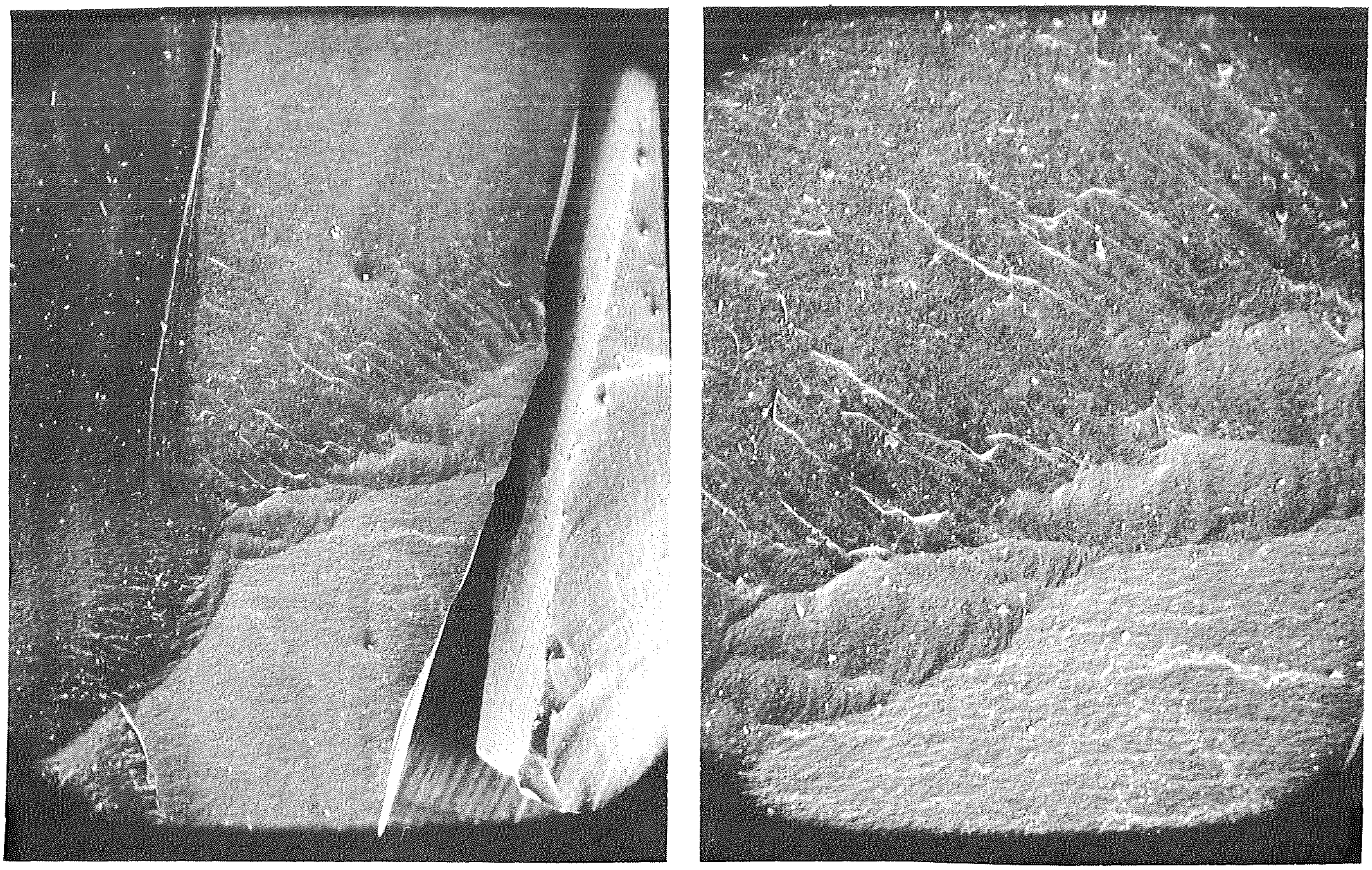
Preparation of New Composition Glass Fibers

Up to this quarter, determinations of the Young's modulus of the glass fibers of this program were carried out by outside agencies. At the start of this quarter a change in this policy was made and UARL purchased the type of fiber modulus equipment which had been used to evaluate our specimens at Panametrics. As a result, although glass fibers have been prepared from glasses UARL 300, 414, 433, 434, 438, 448 and 449, no measurements have been made on the modulus of these fibers. Such measurements are planned for the next quarter.

A Computer Program for the Calculation of Young's Modulus on Bulk Glass Samples

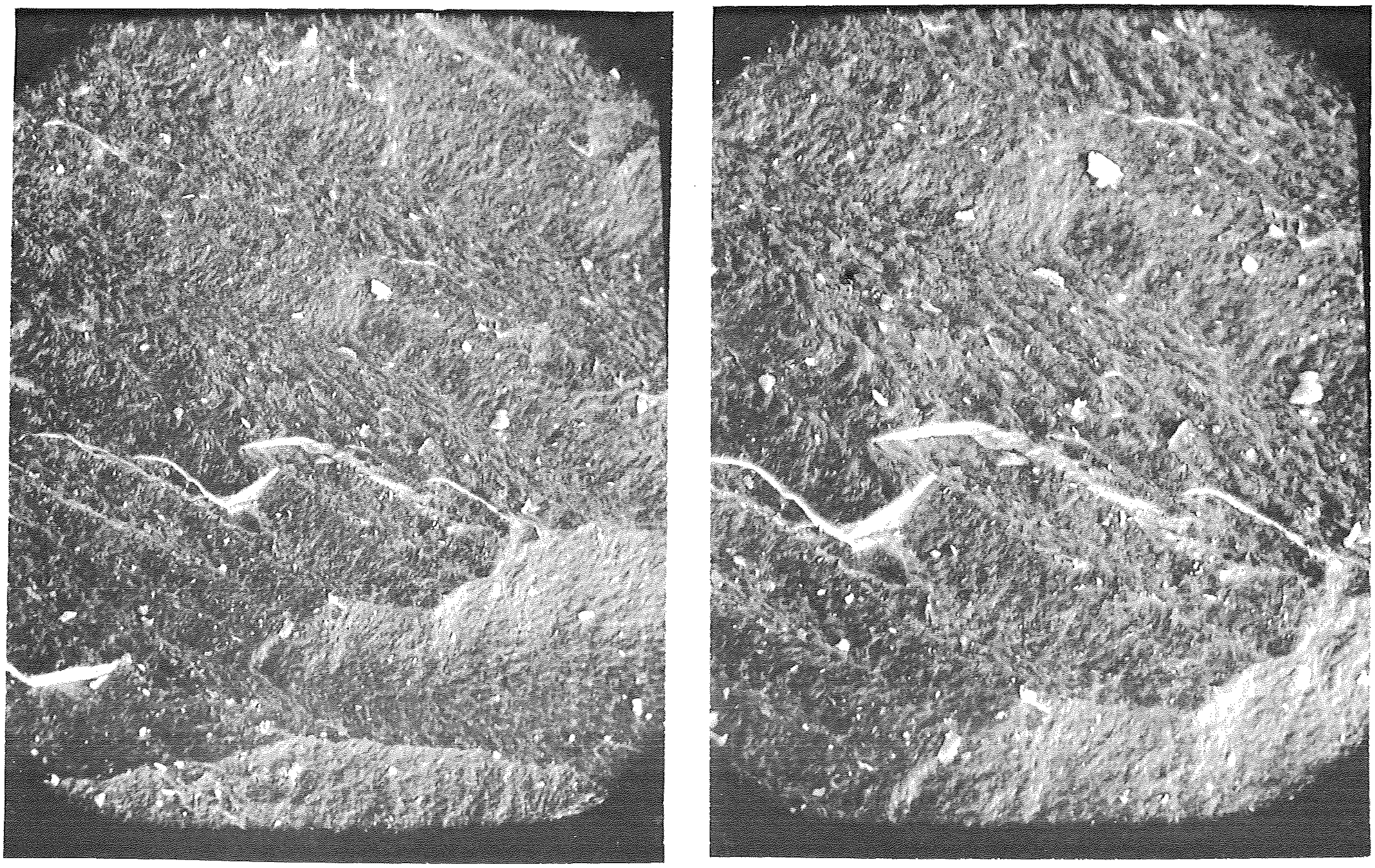
A technique for the determination of the elastic modulus of a material in the form of a cylinder requires the determination of the resonant frequency of the specimen. This technique, as discussed by Pickett (Ref. 1) has been used with a computer program to perform the calculations.

FIG. 4



AREA B 35X 9608

AREA B 85X 9608



AREA B 200X 9608

AREA B 500X 9608

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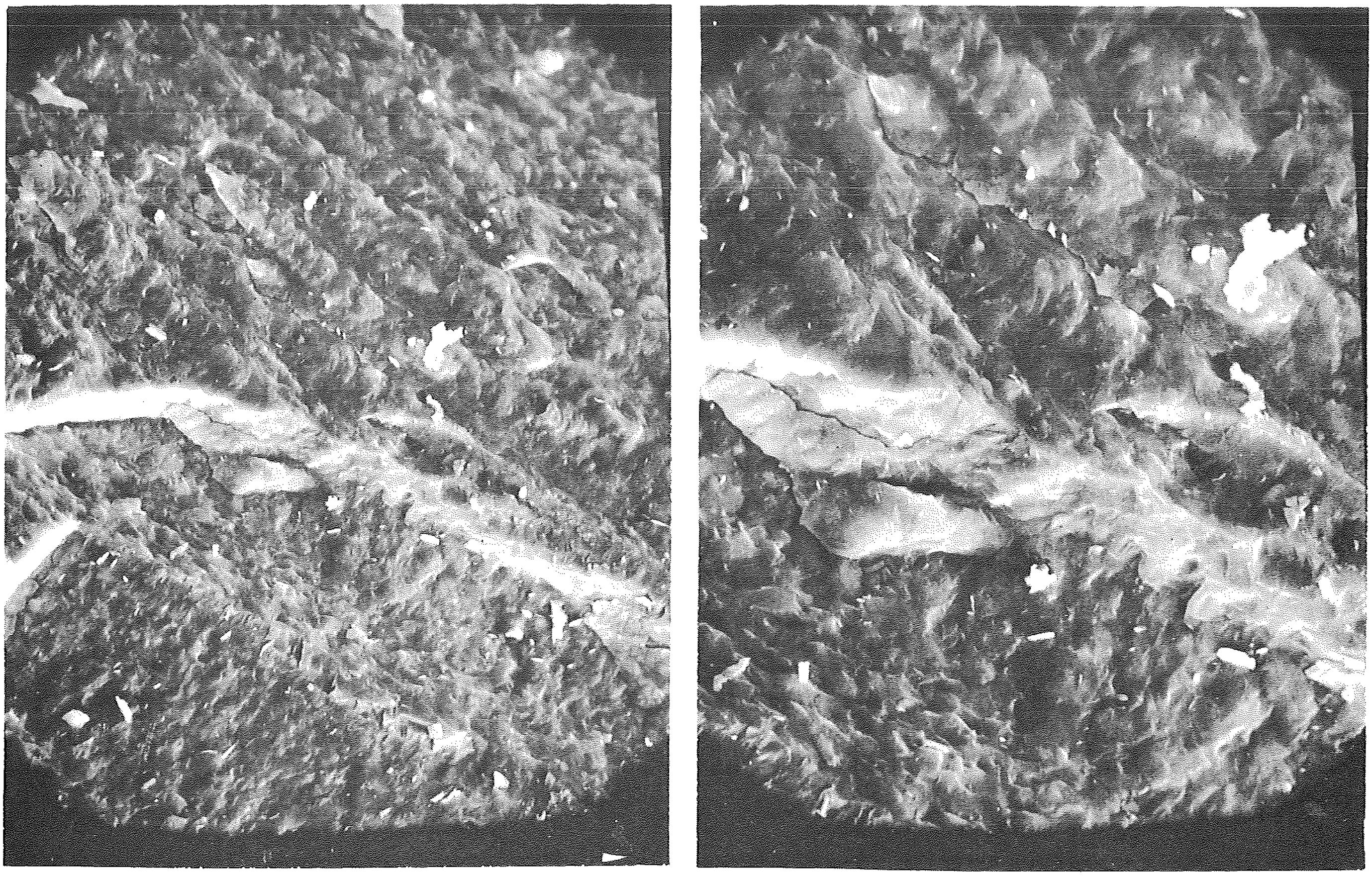
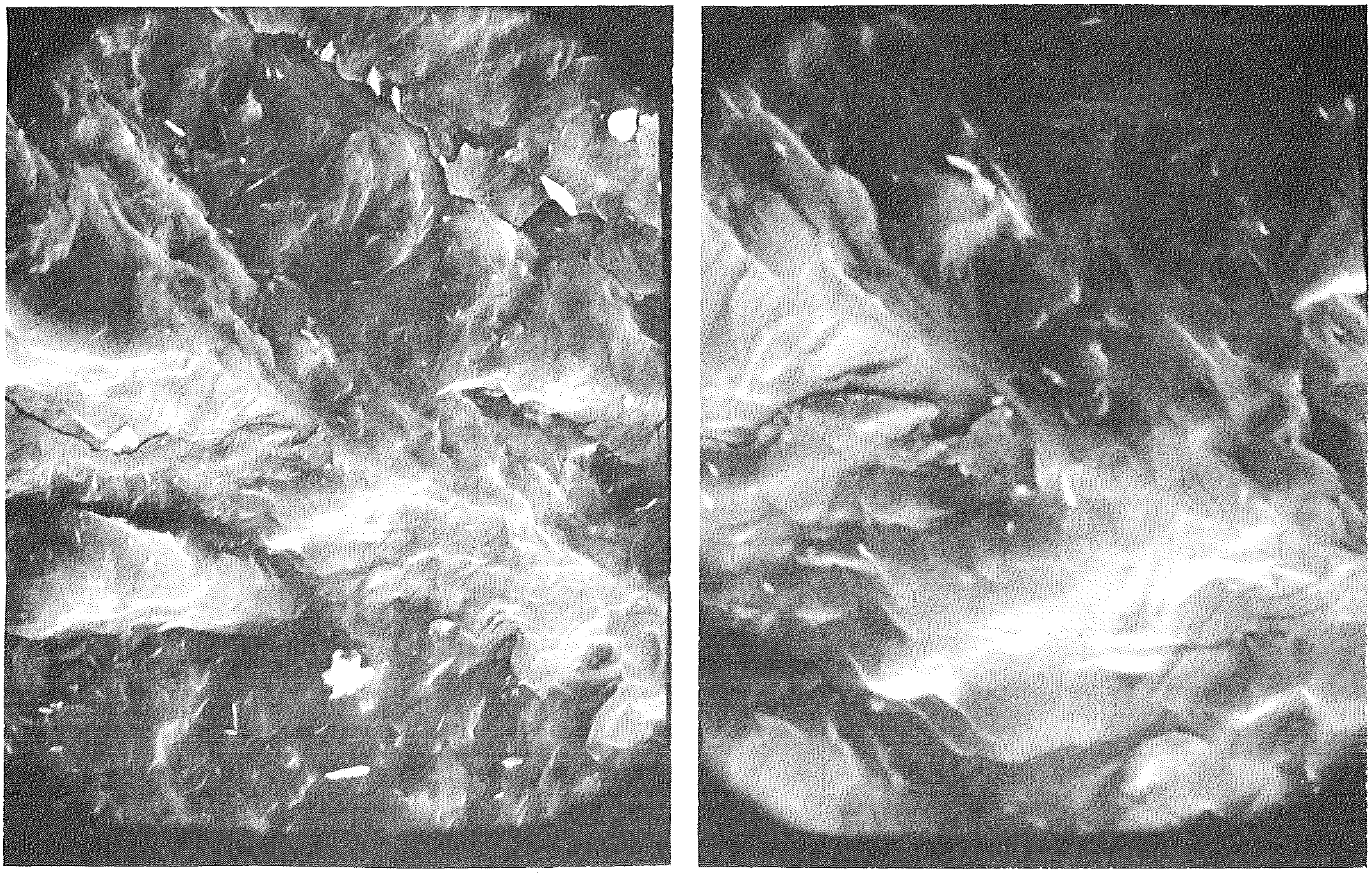
FIG. 5



AREA B 1000X 9608

AREA B 2000X 9608



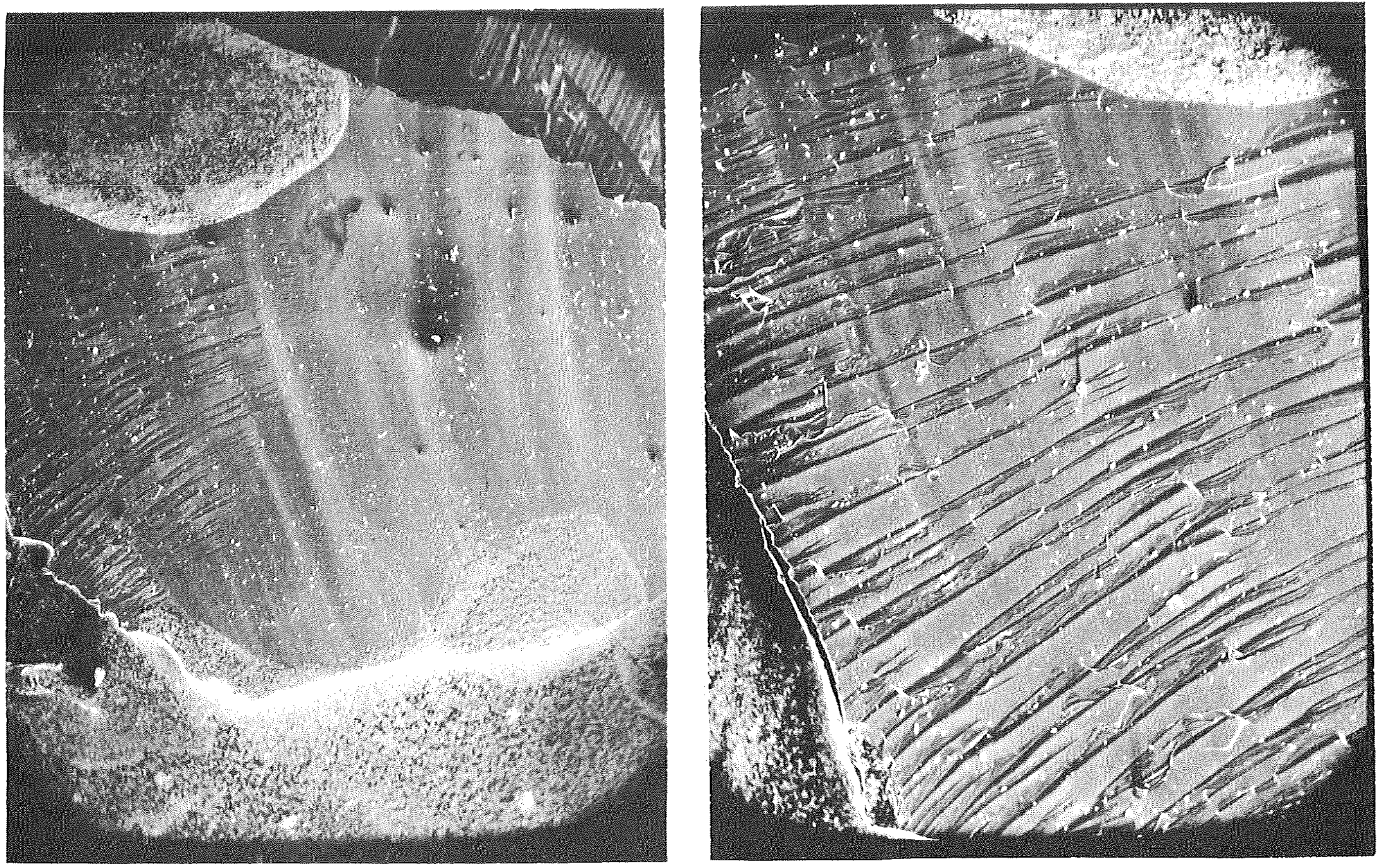
AREA B 5000X 9608

AREA B-1 10,000X 9608

FIG. 6

AREA A UARL 344-35X

AREA A UARL 344-85X



AREA A-1 UARL 344-200X

AREA A-1 UARL 344-500X

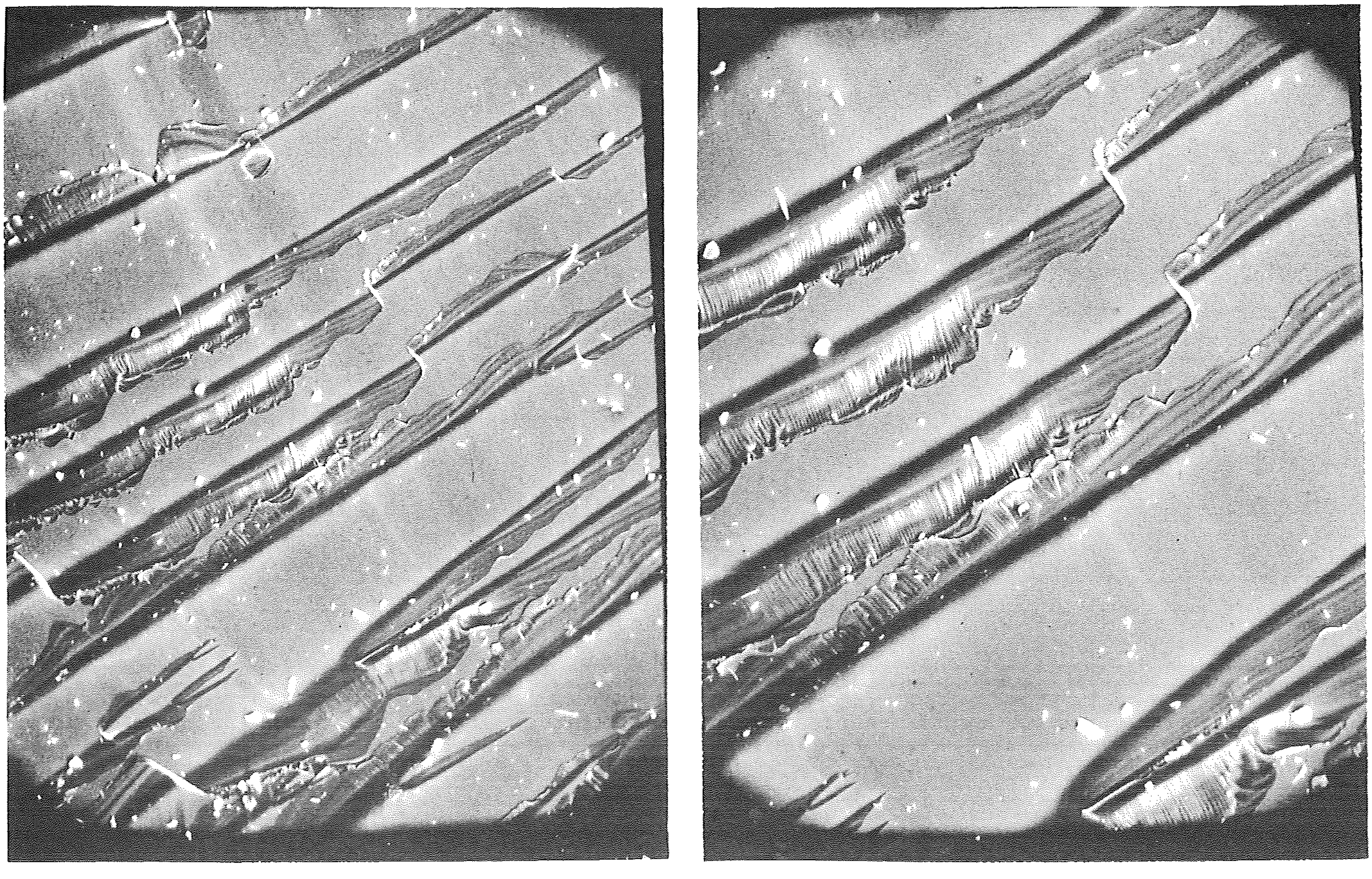
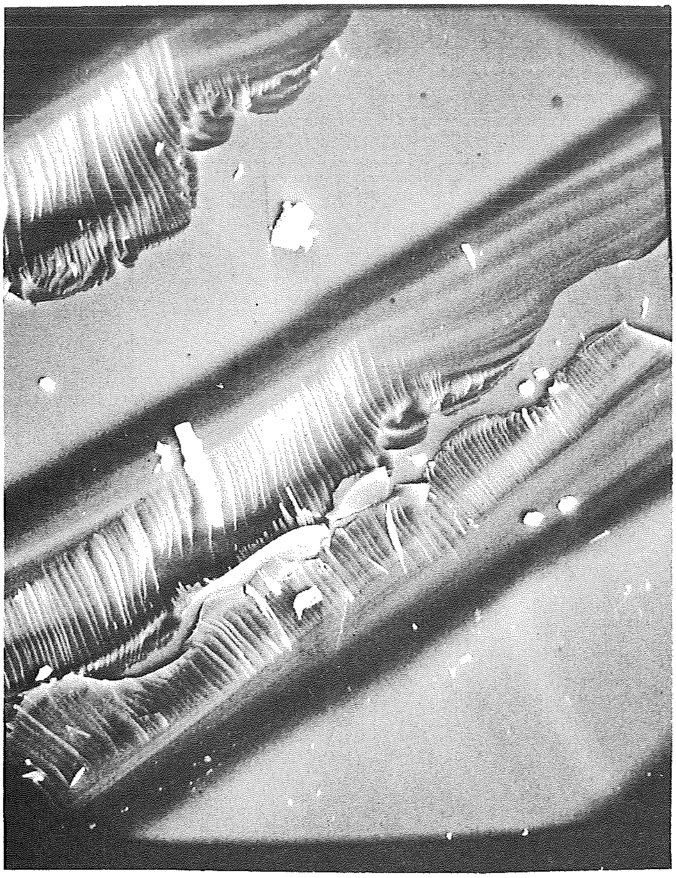
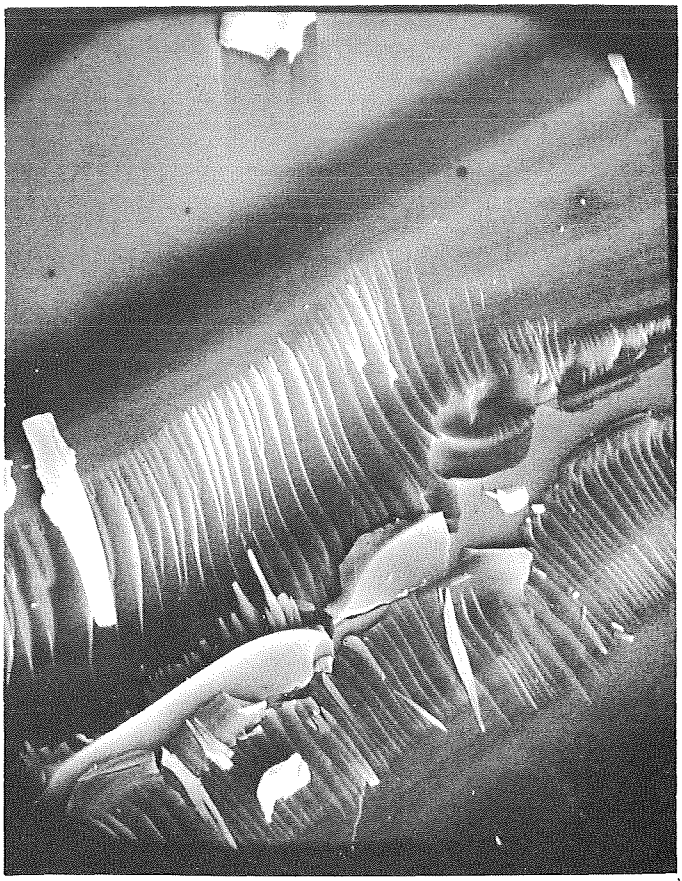


FIG. 7

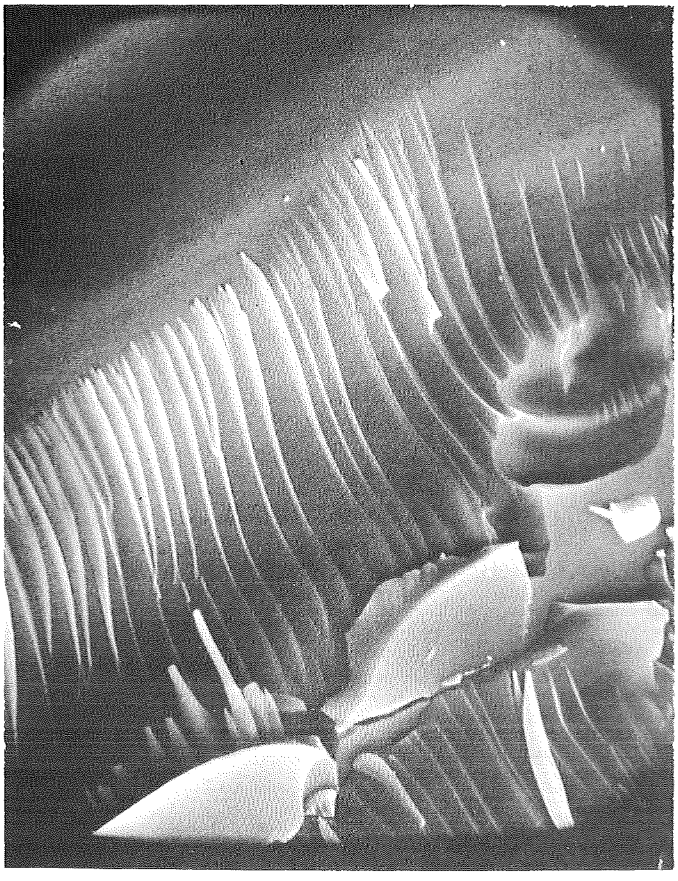
AREA A-1 UARL 344-1000X



AREA A-1 UARL 344-2000X



AREA A-1 UARL 344-5000X



AREA A-1 UARL 344-10,000X

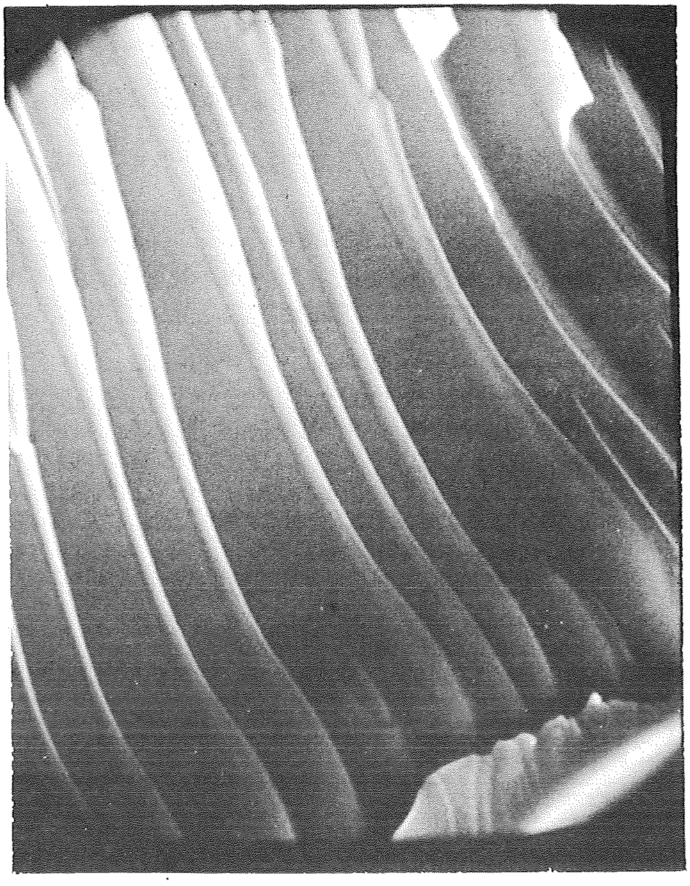


Table V

Preliminary Data on Comparative Impact Tests of Some of the New UARL Glasses in Bulk Form

Glass Number	Average Impact Value (inch pounds)	Young's Modulus (millions psi)
Pyrex Sight Glass (C.G.W. 7740)	0.45	9.3
UARL 304	0.78	19.2
UARL 344	0.66	20.3
UARL 459	0.48	16.5

all test data based on half-size notched Charpy impact tests

The determination of the elastic modulus simply requires the evaluation of the following expression:

$$E = (C)\ (\text{weight})\ (\text{resonant frequency})^2.$$

The constant C is evaluated according to the expression

$$C = 0.0041632\ (L/D)^3\ T$$

with the parameter T evaluated for the diameter and length of the specimen according to

$$T = 1.0 + 81.79(D/2L)^2 - (1314(D/2L)^4)/(1 + 81.09(D/2L)^2) - 125(D/2L)^4.$$

For this calculation, Poisson's ratio has been taken as 1/6, and the factors T and C are those which yield an approximate solution to the differential equations for transverse vibrations as determined by Goens.

In addition to the straightforward calculation, a feature of the program used is a subroutine which can be used to sort the output data in terms of any desired parameter, such as sample diameter. With this feature, checks for systematic variations in calculated modulus values with a chosen parameter can easily be made. The program itself is written in FORTRAN IV for use with a time-shared computing system. The Research Laboratories provides this capability by either an in-house PDP-6 (Digital Equipment Corp.) computer, or by subscription to the General Electric time-shared computing system.

```
CCCC PRØGRAM TØ CALCULATE GLASS BULK MØDULUS BY THE FØRMULATIØN OF PICKETT
CCC INPUT DATA GLASS IDENTIFICATIØN, WEIGHT IN GRAMS, DIAMETER
CCC IN INCHES, LENGTH IN INCHES, RESØNANT FREQUENCY IN KILØCYCLES
CCC
CCC
  DIMENSIØN DIA(50),WT(50),RF(50), E(50)
  DIMENSIØN INDEX(50)
  REAL LE
  ALPHA TITLE
  DIMENSIØN TITLE(10), LE(50)
  READ("PICKVAL",81)NTØT,TITLE
  81 FØRMAT(5X,13,10A4)
  READ("PICKVAL",85)(WT(N),DIA(N),LE(N),RF(N), N=2,NTØT)
  85 FØRMAT(5X,4F10.4)
  NN = NTØT -1
  DØ 50 N=2,NTØT
  M = N-1
  INDEX(M) = M; WT(M)=WT(N); DIA(M)=DIA(N);LE(M)=LE(N);RF(M)
 & = RF(N)
  50 CØNTINUE
  DØ 55 N = 1,NN
  A = DIA(N)/(2.*LE(N))
```

```
  T=1. + 81.79*A**3 - 131.4*A**4/(1. + 81.09*A**2) -
 & 125.*A**4
  C = 0.004163/DIA(N) * (LE(N)/DIA(N))**3 * T
  E(N) = C * (WT(N)/453.59) * RF(N)**2
  55 CØNTINUE
  CALL SØRT( DIA, NN, INDEX )
  PRINT 123, TITLE
  123 FØRMAT(1H , 10X,10A4)
  PRINT," "
  PRINT,"  J  L    DIA     LENGTH     WEIGHT      FREQ
 &      MØDULUS"
  DØ 501 J=1,NN
  L = INDEX(J)
  PRINT 135,J,L,DIA(J),LE(L),WT(L),RF(L),E(L)
  501 CØNTINUE
  135 FØRMAT(1H ,2I3,3F10.4,2F14.4)
  STØP; END
  SUBRØUTINE SØRT( A, NPØINTS,INDEX)
CCC INDEX IS FILLED WITH INDEXING INTEGERS FRØM 1 TØ NPØINTS
CCC ARRAY IS BRØUGHT IN AS A SINGLY SUBSCRIPTED ARRAY
  DIMENSIØN A(50),INDEX(50)
  M = NPØINTS
  1 M = M/2
    1F ( M .EQ. 0 ) RETURN
    K = NPØINTS - M
    J = 1
  2 I = J
  3 IM = I + M
    IF (A(I) - A(IM)) 5,5,4
CCC SWITCH VALUES AND ARRANGE INDEX ARRAY
  4 SAV = A(I); NSAV = INDEX(I)
    A(I) = A(IM); INDEX(I) = INDEX(IM)
    A(IM) = SAV ; INDEX(IM) = NSAV
    I = I - M
    IF (I .GE. 1) GØ TØ 3
  5 J = J+1
    IF ( J-K ) 2,2,1
    END
```

CONCLUSIONS AND FUTURE PLANS

1. It has now been shown that the UARL 344 (beryllia-containing) glass composition can be successfully processed in a multihole (six-hole) platinum-rhodium bushing to produce continuous glass fibers at reasonable rates of speed such as 5000 ft/min. Coupled with the facts that these glass fibers in monofilament form showed a Young's modulus of 18.6 million psi, a specific modulus of 157 million inches, and a probable strength of around 770,000 psi, this glass should

offer an attractive commercial product. Additional tests with UARL 344 glass fiber-epoxy resin composites including tensile strength, compressibility, static-fatigue, and boiling water tests on composites fabricated with experimental sizes should fill in the picture of the usefulness of this glass.

2. The directions in which we are altering the compositions of our nonberyllia containing glasses have sufficiently modified the working characteristics of such glasses so as to support the hope that a nonberyllia glass composition at least as useful as the UARL 344 composition will evolve.

3. Preliminary examination of the impact characteristics of the UARL glasses and epoxy resin-UARL glass fiber composites indicate that a much more careful examination of all our prior glass compositions is in order since the glasses examined showed enhanced impact resistance. These studies also indicate that our highest modulus glasses are probably not our strongest and additional studies of the strength of some of the earlier UARL compositions are clearly needed.

PERSONNEL ACTIVE ON CONTRACT IN THIS PERIOD

Personnel active on the program throughout the second quarter have been James F. Bacon, Principal Investigator and Francis Hale, Experimental Technician. In addition, Mr. Roy Fanti and Dr. Michael DeCrescente of United Aircraft have closely followed the program and have used their influence in getting additional work done on the properties of this glass over and beyond that which could be carried out under the contractual funds. Mr. Richard Novak of UARL was instrumental in the fabrication and testing of the composite specimens for impact. Dr. Charles Rau of P&WA Advanced Materials and Development Laboratory carried out the impact testing of the bulk glass samples. Dr. Frank Douglas of UARL developed the program for calculating Young's modulus of bulk glass samples and applied it to a number of our glasses.

Liaison throughout this program and the prior programs has been constantly and regularly furnished by Peter H. Stranges of the UARL Washington Office. Throughout this period and the earlier programs, UARL personnel have reported progress to and received friendly, courteous, and helpful advice from James J. Gangler of NASA/OART Washington Headquarters.

REFERENCE

1. Pickett, Gerald, Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibrations of Prisms and Cylinders, Amer. Soc. Testing Materials, Proc. 45, 846-63 (1945), discussion pp 864-65.