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SYNTACTIC FOAM
EVALUATION

BDX-613-177

March, 1971

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Final Report

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ABSTRACT

The mechanical, physical, and chemical properties of the Imidite SA syntactic foam system (Whittaker Corporation) were studied, to attain this objective:

- To develop material and quality control information for a syntactic foam which would meet design requirements.

Using Imidite SA powder (prepared from Imidite 2801 prepolymer, silica microballoons, and ceramic fibers), foam billets were fabricated and tested. Results of tests showed that the billets met these requirements:

- Density 31.5 to 38.5 pounds per cubic foot
- Thermal conductivity at 500°F,

$$1.3 \frac{\text{BTU/in.}}{\text{Hr/Sq Ft/°F}} \quad \text{Max}$$

- Compression strength at 500°F, 2400 psi minimum
- Tensile strength at 500°F, 750 psi minimum
- Shear strength at 500°F, 900 psi minimum
- Flexural strength at 500°F, 1000 psi minimum.

Materials Specification 2144060 was prepared, based on the test results.

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SUMMARY

This program was initiated to develop and establish material, design, and quality data on a syntactic foam system. Design requirements had created the need for a foam which was resistant to high temperatures and which had good insulation and structural properties at high temperatures. A syntactic foam system (Imidiate SA, Whittaker Corporation, San Diego, Calif.) had been selected for the part (Pedestal); however, the material was being sold for development uses only, since limited test data was available. A contract was placed with Whittaker to do additional development work with the material and to establish lot-to-lot quality control data so that the material could be supplied in a consistent quality and could be processed satisfactorily into parts.

The bulk of the development work was done by the supplier at his facility. Samples of specified lots were submitted by the supplier to BKC for in-plant material development work and for correlation with data developed at Whittaker. All the thermal conductivity specimens fabricated at Whittaker and BKC were tested at BKC because Whittaker didn't have facilities for this kind of testing. The information derived from this cooperative effort provided data which was used for design criteria and for establishing the molding process and material requirements for the material and design specifications. Figures 1 through 6 illustrate the material and equipment used at BKC in the development program.

Variables which most affected the physical properties of the material were: variations in lots of Imidite 2801 prepolymer; the degree of cure; and the fiber orientation in the Imidite SA molded foam. To minimize other variations, the microballoon content, fiber content, cure cycle, and filler-resin ratio were held constant. These initially established values were considered satisfactory for development of data among the four different lots of Imidite 2801 prepolymer constituent of the molded foam (See Table 1).

The tensile strength data within a given lot or batch showed good correlation; however, between lots of prepolymer 2801 there was a much greater variation. Differing densities for some of the specimens within a given lot or billet were caused by the method of measuring dimensions. Comparison of flexural strength data showed much better correlations in strength and densities than did the tensile data. Shear data showed more variation than expected and was dependent on testing techniques. The heat distortion data looked very encouraging, with good correlation between Bendix and Whittaker.

In the testing of compression strength, the same method of testing was used by Bendix (BKC) and Whittaker (W.C.); however, different methods of reporting the results were used. The results reported by Bendix represented compressive strength at the yield point; the compressive results reported by Whittaker were the maximum values, which were higher.

The compressive strengths, tested at room temperature, were 600 to 1000 psi higher for the horizontal molded specimens than the vertical molded specimens. This indicates that the material is direction dependent and the strength is dependent upon orientation of the fibers in the billet. The orientation of the fibers also appears to be dependent upon how the material is loaded in the mold.

Text continued on Page 9.

Figure 1. Sketch of Vacuum Plate Assembly and Mold

Figure 2. Imidite SA Molding Compound

Figure 3. Vacuum Plate Assembly with Mold

Figure 4. Mold Assembly and Test Block

Figure 5. Interior of Oven, Showing: Blanket Clamped on Mold Assembly, Heat Sensor, and Vacuum Line for Volatiles

Figure 6. Exterior of Oven, Showing Vacuum Pump and Tube Trap for Volatiles

PROCESS DESCRIPTION FOR MOLDING IMIDITE SA

GENERAL DESCRIPTION

A description of the equipment, molds, and processes used in the BKC Materials Laboratory, to mold the Imidite SA powder, is listed in the following paragraphs.

Equipment Used

- Vacuum pump capable of 0.5 to 3 mm Hg vacuum
- Manometer, U-tube
- High temperature forced convection cam-controlled oven (850°F capacity)
- Recorder
- Steel retort fitted with approximately 20 to 30 feet of tubing to preheat temperature of argon gas to oven temperature
- Miscellaneous items:

Metal tubing, rubber hose, C clamps, cold traps

High temperature vacuum grease

Dry ice for cold trap, or liquid nitrogen

Glass cloth

Silicone rubber, Kapton film, or other high temperature thin, flexible sheet which can be used for application of vacuum

High temperature mold release

Heavy screen wire

- Molds

Molds consist of these sections:

Flat steel plate on bottom (1/2 inch thickness)

Steel frame plate on plate (1/2 inch wall)

Steel block which slides on interior of frame

Thin metal plate (1/16 inch or less)

- Vacuum Plate and Frame

An aluminum plate $3/4$ inch thick which fits into oven and has a vacuum port near edge of where mold is placed.

An aluminum frame made from $5/8$ inch thickness by $1-1/2$ inch width bar stock, welded on ends to fit flush with outside of plate and flat to aluminum plate.

Process Information

- Mold release all sections of the mold and then place frame over bottom plate. Use tape on sides to hold in place.
- Pre-weigh the required quantity of powder into the mold. It is loaded to a uniform depth in the mold. Light hand packing may be used.
- A thin (0.30 to 0.060 inch) plate which fits into the frame can be placed over the material. Place the steel block over the thin plate.
- Set the assembly on the vacuum plate and cover it with several layers of glass cloth. Lay two or three thicknesses of screen wire over the vacuum port and under the glass cloth.
- If silicone rubber is used, drape it over the assembly, then work the frame into place. Some effort is required in removing the wrinkles in the silicone. Use vacuum grease on the plate, if necessary. Clamp frame in place.

If Kapton film is used, place a gasket of silicone rubber on the outer extremities of the plate (approximately 2 inch width). Use vacuum grease on both sides of the gasket. Drape the Kapton film over the assembly and fold it at the four corners. Another gasket of silicone rubber, the size of the frame, is greased on top side so as to stick to the frame. Place frame, with the silicone rubber side down, over the assembly and clamp into place.

Note: The silicone rubber sheet will withstand about 2 cycles up to 600°F , whereas the Kapton film lasts indefinitely.

- Place the mold assembly in the oven and apply vacuum. Maintain vacuum at 0.5 to 5 mm Hg throughout the cure cycle. Attach the manometer directly to the vacuum plate or to the line leading from the oven.

- The oven is turned on and the cycle controlled as follows:

30 minutes $\pm$ 10 minutes at $250 \pm 10^\circ\text{F}$
40 minutes $\pm$ 10 minutes at $300 \pm 10^\circ\text{F}$
60 minutes $\pm$ 15 minutes at $350 \pm 15^\circ\text{F}$
60 minutes $\pm$ 15 minutes at $400 \pm 15^\circ\text{F}$
60 minutes $\pm$ 15 minutes at $450 \pm 20^\circ\text{F}$
60 minutes $\pm$ 15 minutes at $500 \pm 20^\circ\text{F}$
60 minutes $\pm$ 15 minutes at $550 \pm 20^\circ\text{F}$
30 minutes $\pm$ 10 minutes at $600 \pm 20^\circ\text{F}$

Total - 6 hours 40 minutes $\pm$ 40 minutes

Note: A room temperature trap is required in the vacuum line, approximately 4 inches from port in oven. This will eliminate the formation of crystals in the vacuum line and the plugging of the vacuum.

Locate a dry-ice cold-trap somewhere in the line, to catch any volatiles which bypass the first trap.

- Post Cure

Set test blocks on 1/4 inch steel plates, with one layer of glass cloth between specimen and plate.

Place the blocks in a steel retort fitted with lid, and 20 to 30 feet of tubing for preheating the argon gas to oven temperature before entering the retort. The argon gas enters near the bottom of the retort.

The retort is purged continuously during the post cure cycle and until the oven cools to at least 300°F .

- Post Cure Cycle

120 minutes $\pm$ 15 minutes rise time from room temperature to $600^\circ\text{F} \pm 20^\circ\text{F}$
60 minutes $\pm$ 10 minutes rise time from $600^\circ\text{F} \pm 20^\circ\text{F}$ to $700 \pm 20^\circ\text{F}$
20 minutes $\pm$ 5 minutes at $700 \pm 20^\circ\text{F}$
60 minutes $\pm$ 10 minutes rise time from $700^\circ\text{F} \pm 20^\circ\text{F}$ to $800 \pm 20^\circ\text{F}$
20 minutes $\pm$ 5 minutes at $800 \pm 20^\circ\text{F}$
30 minutes $\pm$ 10 minutes rise time from $800^\circ\text{F} \pm 20^\circ\text{F}$ to $850^\circ\text{F} \pm 20^\circ\text{F}$

Total - 5 hours 10 minutes $\pm$ 20 minutes

Turn off oven.

- Allow test blocks to cool to 300°F or lower before removing from the argon purged retort. Store test blocks in a dry atmosphere.

TEST ANALYSIS

DETERMINATION OF MECHANICAL AND THERMAL PROPERTIES, BY ASTM STANDARDS

Specimens were tested according to the appropriate ASTM standard; the results obtained were tabulated. Billets were identified by polymer lot number and by batch number (Table 1). Methods of testing were:

- Determine the weight and density of each specimen. Report density in pounds per cubic foot and weight in grams.
- Tensile strength per ASTM D638. (Table 2)
Note: Test specimen 1-5 at room temperature
Test specimen 6-10 at 500°F

Report:

Max load, in pounds
Maximum stress, psi
Strain at max stress, in percent
Elastic modulus, $\text{psi} \times 10^5$

- Flexural strength per ASTM D790 (Table 3)
Note: Test specimen 1-5 at room temperature
Test specimen 6-10 at 500°F

Report:

Max load, in pounds
Maximum stress, psi
Deflection at max stress, in inches
Elastic modulus, $\text{psi} \times 10^5$

- Shear strength per ASTM D732 (Table 4)
Note: Test specimen 1-5 at room temperature
Test specimen 6-10 at 500°F

Report:

Max load, in pounds
Max stress, psi
Strain at max stress, in percent
Elastic modulus

- Compressive strength per ASTM D1621 (Tables 5, 6, and 7)
Note: Test specimen 1V-5V and 1H-5H at room temperature
Test specimen 6V-10V and 6H-10H at 500°F

Report:

Max load, in pounds

Max stress, psi

Strain at max stress, in percent

Elastic modulus, $\text{psi} \times 10^5$

- Heat distortion temperature per ASTM D648 (Table 8)

A modification of the standard method was necessary because of the extremely high heat distortion temperature which is experienced.

The method used by Whittaker Corporation can be described as follows:

Temperatures were taken from a thermocouple placed in a hole drilled in the specimen.

The specimens were placed in an oven at 500°F for 264 psi loading; the load, calculated by the method described in the ASTM procedure, was applied 2 minutes after the specimen reached temperature.

The specimens were heated in an air oven at 5 degrees per minute.

The heat distortion temperature was considered as that temperature where the specimen deflected 0.010 inch, assuming zero deflection at the starting temperature.

TENSILE STRENGTH

The tensile strength of all specimens was tested according to ASTM D638. (See Figures 7 and 8, and Table 2.) There is a wide variation in the tensile strengths and densities of the four different lots of Imidite 2801 prepolymer. The strength increased with increasing density at both room temperature (R. T.) and at 500°F. Specimens from lot 89 showed the highest strengths, while those from lot 92 were the lowest.

The variation in the four different lots of Imidite 2801 prepolymer appeared to be much greater than the results of the four batches of Imidite Powder made from lot 91. Billets 1, 7, 8 of Imidite Powder 91-1 showed less variation in density than the other billets from lot 91.

When the tensile strengths of billet 2A (made at W. C. and tested at BKC) was compared with billet 2 (made and tested at Whittaker) the density was about 4 lb/cu ft higher on the billet sent to BKC; billets 4 and 4D tested similarly. The difference is a result of the method of calculating the volume of the irregular specimen. The corresponding tensile strengths are approximately the same for the billets from the corresponding powder batches. Billet 3 (made and tested at Whittaker) compared with billet 3A (made and tested at Bendix), showed corresponding tensile strength; however, densities were again about 4 lb/cu ft different.

In summary, the test results for all tensile strength specimens show good correlation; however, there is a difference in results for densities measured by W. C. and BKC for the tensile specimens.

FLEXURAL STRENGTH

The flexural strength was determined per ASTM D790. (See Figures 9 and 10, and Table 3.) The density variation was again much greater between lots, with lot 89 (billet 6) being the highest at approximately 38 lb/cu ft and lot 92 (billet 9) being the lowest at 32 lb/cu ft. The variation in strength between polymer batches was exemplified by: the strength of lot 89, billet 6, was around 3000 psi at R. T.; the strength of lot 92, billet 9, was almost 1200 psi lower, at 1800 psi.

The three billets made from lot 91-1 showed good correlation within a given batch of powder. The correlation is fair among the four Imidite powder batches prepared from lot 91. The densities were within 1-1/2 to 2 lb/cu ft, while the strengths at room temperature varied between 2300 and 3300 psi.

When the flexural strength of billet 2A (made at Whittaker and tested at Bendix) was compared with billet 2 (made and tested at Whittaker), the strength at room temperature was within 100 psi while the strength at 500°F correlated almost exactly at 2430 psi. The average density of the specimens tested at Bendix from billet 2A was approximately 1 lb/cu ft greater than reported by Whittaker from billet 2; this is considered good agreement. The strength of billet 3 (molded and tested at Whittaker) was about 150 psi higher than billet 3B (molded and tested at BKC) at 500°F, while at R.T. the strength was almost 600 psi higher. Billet 3B density was about 1 lb/cu ft higher.

Billet 4D (made and tested at Bendix) showed strength about 150 psi higher than billet 4 (made and tested at Whittaker), when tested at R.T. and at 500°F. The density of 4D was also about 1 lb/cu ft higher than billet 4C, which was made at Whittaker and tested at Bendix. In comparing 4C with 4 at 500°F, it was found that the strength for billet 4C was about 200 psi higher while the density remained the same.

There was uniformity in flexural tests within a given batch of prepolymer, whether made or tested at Bendix or at Whittaker. The specimens from billets made at BKC are denser by about 1 lb/cu ft.

SHEAR STRENGTH

The shear strength of all specimens was tested per ASTM D732. (See Figures 11 and 12, and Table 4.) Comparison of lots 89 through 92 shows about the same variations as with the tensile and flexural tests. There are more inconsistencies in the data, indicating that there are some testing parameters more difficult to repeat.

Specimens from billet 7 tested at room temperature are approximately 1-1/2 lb/cu ft below specimens tested at 500°F; specimens from billet 4D showed the same type of density variation. Specimen density should be the same whether tested at room temperature or 500°F, since they were picked at random from the same block. Other specimens from billets 6, 9, 2A, and 4C showed consistent density, whether tested at room temperature or 500°F.

Another correlation which was noted was that the strength of a specimen tested at Bendix was nearly the same, whether tested

at R.T. or 500°F. Specimens tested at R.T. at Whittaker were about 200-500 psi higher than specimens tested at 500°F; this correlates with results obtained from the other tests. The range of strengths reported for R.T. is 1100-1850 psi, while the range at 500°F is 950-1350 psi.

Shear strength test results vary more than those of tensile or flexural strength. The use of shear strength as a test for a lot-to-lot acceptance standard does not appear to be desirable.

COMPRESSIVE STRENGTH (VERTICAL DIRECTION)

The results for the compressive strengths described here were for specimens with the length parallel to the direction of molding. The compressive strengths of all specimens were determined per ASTM D1621 on 0.5 by 1 - inch specimens. (See Figures 13 and 14 and Table 5.) Horizontal specimens were much stronger in compression than vertical specimens.

The compressive strength in the vertical direction increases with increasing density. Comparisons of billets 1, 7, and 8 show relatively good agreement in strength at both temperatures tested; however, the density varies almost 2 lb/cu ft between billets 1 and 8. In comparing the four batches of Imidite SA powder (from lot 91 made and tested at Whittaker) it was found that the results at room temperature varied about 550 psi between the high and low; the variation among billets 1, 7, 8, 2, 3 and 4 from lot 91 of prepolymer was only 2.5 lb/cu ft.

The strength at room temperature of billet 2 (made and tested at Whittaker) was about 1100 psi higher than that reported for billet 2A (which was made at Whittaker and tested at Bendix). The reason for this is that the compression results reported by Whittaker are maximum values, while those reported by Bendix are compressive yield strengths.

In general, at room temperature the results for the horizontal specimens are from 600-1000 psi higher than the vertical specimens. At 500°F the results of horizontal specimens are about 300-900 psi higher than the vertical specimens. This is a significant difference and could account for some of the variations.

The material strength is direction dependent, which is caused by the orientation of the fibers in the composite. The orientations of the

fibers are such that the strength of the horizontal specimen is greater than the vertical specimen. The orientation, which is dependent on both the mold loading technique and the method of compacting, is believed to take the directions shown in Figure 15. In the horizontal specimen, the fibers can be longer and there is less cutting or breakage of fibers during machining. The fibers of the horizontal specimen are parallel to both the long axis (1 inch dimension) and the short axis (0.5 inch dimension).

The fibers in the vertical specimen would be parallel to only the short axis. Likewise, the fibers would be shorter.

At the beginning of the program, the importance of the fibers and the orientation was not considered significant; however, after developing the test data, it appears to be extremely important. The fiber orientation in the composite and the Imidite 2801 prepolymer are two very important variables affecting the physical properties of the material. Other parameters which are considered significant are microballoon density, cure cycle, and filler-resin ratio; however, these parameters were held constant in the work conducted under this process development order.

COMPRESSIVE STRENGTH (HORIZONTAL DIRECTION)

In the four different lots of Imidite 2801 prepolymer, there is a significant variation in strength with a change in density. Billets 1, 7, 8 of batch 91-1 show good uniformity in strength, with only 1-1/2 pounds difference (See Figure 16 and Tables 6 and 7.) The strength of billet 2A was about 400 psi less than billet 2; both were made at Whittaker and 2A was tested at Bendix. At 500°F the difference was only 150 psi.

Billet 3 (made and tested at Whittaker) compared with billet 3B (made and tested at Bendix), showed excellent agreement of strength at 500°F; at room temperature billet 3 tested about 700 psi higher.

Billet 4C (made at Whittaker and tested at BKC) data was quite similar to results obtained from billet 4D (made and tested at BKC). Billet 4 (made and tested at Whittaker) tested 900 psi higher at room temperature than either billet 4C or 4D; at 500°F billet 4 was 500 psi higher.

To conclude, this data also follows the trend of increasing strength with density, with more variation at R. T. than at 500°F.

The compressive strength property reported by BKC was compressive yield strength; that reported by Whittaker was the maximum compressive strength. The maximum yield strength is obtained around 1 to 2 percent deflection, where there is a yield, while the maximum strength could occur as high as 30 to 40 percent deflection. Likewise, the value recorded for maximum strength would be as high or higher than that reported for yield strength. At 500°F the variation between the test results would not be nearly as great and the two values should be nearly the same. The results appear to substantiate this explanation.

HEAT DISTORTION TEMPERATURE

The heat distortion temperature was determined by a modification of ASTM D648. (See Figure 17 and Table 8.) The test is a measurement of the temperature at which a test bar deflects 0.1 inch with a constant load of either 66 psi or 264 psi. The test can be used as an indicator of the ability of a material to retain its strength at high temperatures, as well as a representation of the degree of cure a material has reached.

On comparing the test results developed at Whittaker, it was found that the heat distortion temperature was directly related to the physical properties of the specimens from the different billets. Specimens which showed a high strength also had a high heat distortion temperature.

The results from Whittaker and from the Bendix Test Laboratory showed excellent agreement. All test results for 264 psi load gave heat distortion temperatures up around 800°F. Billet 9, which was consistently the lowest in all the physical properties, was the lowest at 711°F.

DENSITY VARIATION CONTROL

On comparing the average densities of the specimens machined within a given billet, it was found that there was considerable variation within some billets. (See Table 6). This difference was only

partially due to variation within a billet; the main cause was variation in methods of dimensional measurement and in the calculation of the volume of the specimen. Since the molded material was porous, it was not possible to measure specific gravity; density was measured by weight-volume methods. If the dimensions are not accurately measured, then the variation can be significant. The variations in density for the tensile specimen from billets 2A, 3B, 4C, and 4D (those measured at BKC) were considerably higher than the other specimens within the same billet.

The most significant density variations among the billets tested were between the billets made with the different lots of Imidite 2801 prepolymer. This is as expected, since each lot of Imidite 2801 prepolymer varied in the amount of volatiles evolved during the cure. Without the application of pressure by vacuum or otherwise, the resin would have formed a foam on the application of heat. To form a dense, solid, and uniform billet, it was necessary to apply vacuum for the removal of volatiles, and pressure for compaction of the foam. In the molding of parts to size, density would be dependent upon the processing conditions, as well as the amount of material placed in the mold cavity. Strength would be dependent upon density and the amount of material placed within the cavity. If too much material was placed in the cavity then there would be a possibility of crushing microballoons and increasing the density; the main cause was variation in methods of dimensional measurement and in the calculation of the volume of the specimen.

To eliminate charge weight and pressure effects, vacuum molding was chosen to be used in preparing billets for this program. Additional advantages were: larger billets could be prepared; and all the required specimens could be machined from one billet. Density variation due to processing was kept to a minimum. The cost of tooling was lessened by making large billets and machining specimens from them.

RECOMMENDATIONS

Additional areas where development work can be done to improve the strength of the molded material would be in the cure cycle and the post cure cycle. This work would have to be done on a standard size billet; since small thin billets cure faster than large thick billets, the small billets would be more desirable. Methods of loading the mold should also be investigated further, to determine what can be done to optimize the strength in a specific direction.

Table 1. Billet Identification

Polymer Lot	Batch	Billet	Prepared By	Tested By
89	89-1	6	Whittaker	Whittaker
90	90-1	5	Whittaker	Whittaker
91	91-1	1	Whittaker	Whittaker
		7	Whittaker	Whittaker
		8	Whittaker	Whittaker
	91-2	2	Whittaker	Whittaker
		2A	Whittaker	Bendix
		11	Whittaker	Whittaker
	91-3	3	Whittaker	Whittaker
		3B	Bendix	Bendix
		4	Whittaker	Whittaker
	91-4	4C	Whittaker	Bendix
		4D	Bendix	Bendix
92	92-1	9	Whittaker	Whittaker

Figure 7. Graph of Tensile Strength Versus Density

W_m = The actual (measured) minimum value of the width W . W_m must be within the limits shown for W in the table and must occur at distances of not less than $A/2 \pm 0.06$ from the tangent points. Dimensions are in inches.

Measurement	Dimensions (195B)
t	0.13 to 0.25
A	$2.25 + 0.12$ $- 0.00$
B	0.75 ± 0.06
C	3.12 ± 0.06
L	8.50 ± 0.06
R	3.00 to 3.50
W	0.500 ± 0.005
e	0.001 to 0.003

Figure 8. Tensile Strength Specimen, ASTM D638-58T

Table 2. Tensile Strengths of Specimens

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu ft)	LOAD (Lb)	STRENGTH (Psi)	STRAIN (%)	MODULUS (Psi x 10 ⁵)	TEST TEMP.
3B*	91-3	1	12.5921	36.61	166	1328	0.81	3.03	Room
		2	12.4607	36.23	164	1312	0.96	2.98	
		3	12.4775	36.27	154	1232	0.61	3.22	
		4	13.2059	38.39	199	1592	0.96	3.50	
		5	12.7664	37.12	171	1368	0.98	3.17	
		Avg.	12.7005	36.92	171	1366	0.86	3.18	500°F
		6	12.5335	36.44	166	1328	----	----	
		7	13.1992	38.37	190	1520	----	----	
		8	12.3495	35.90	160	1280	----	----	
		9	12.4811	36.29	170	1360	----	----	
4D	91-4	10*	10.9703	----	162	1296	----	----	Room
		Avg.	12.3067	36.75	170	1357	----	----	
		*Off-size							
		1	13.1993	38.37	175	1400	1.11	3.03	
		2	13.1493	38.23	157	1256	0.94	2.85	
		3	13.0051	37.81	140	1120	0.73	2.89	500°F
		4	13.3193	38.72	180	1440	1.10	3.12	
		5	13.0935	38.07	165	1320	0.89	3.12	
		Avg.	13.1533	38.24	163	1307	0.95	3.00	
		6	13.1368	38.19	159	1272	----	----	
2A**	91-2	7	13.4466	39.09	185	1480	----	----	Room
		8	13.3307	38.76	154	1232	----	----	
		9	13.1591	38.26	165	1320	----	----	
		10	13.4323	39.05	170	1360	----	----	
		Avg.	13.3011	38.67	167	1333	----	----	500°F
		1	12.8056	37.23	160	1280	0.41	3.50	
		2	12.9522	37.66	198	1584	0.59	3.80	
		3	13.0355	37.90	210	1680	0.60	3.70	
		4	13.3395	38.78	213	1704	0.60	4.00	
		5	13.1311	38.18	179	1432	0.51	3.92	
4C	91-4	Avg.	13.0528	37.95	192	1536	0.54	3.78	Room
		6	12.7312	37.01	192	1536	----	----	
		7	12.9024	37.51	199	1592	----	----	
		8	13.1011	38.09	185	1480	----	----	
		9	12.6030	36.35	188	1504	----	----	500°F
		10	12.8563	37.38	202	1616	----	----	
		Avg.	12.8188	37.27	193	1546	----	----	
		1	12.3045	35.77	157	1256	0.73	3.07	
		2	12.2883	35.72	151	1208	0.52	3.57	
		3	12.4595	36.22	151	1208	0.55	3.22	Room
4C	91-4	4	12.4269	36.13	150	1200	0.54	3.12	
		5	12.7899	37.18	192	1536	0.90	3.50	
		Avg.	12.4538	36.20	160	1282	0.65	3.30	
		6	12.1658	35.37	150	1200	----	----	500°F
		7	12.2227	35.53	159	1272	----	----	
		8	12.7228	36.99	188	1504	----	----	
		9	12.6031	36.64	179	1432	----	----	
		10	12.2389	35.58	157	1256	----	----	
		Avg.	12.3907	36.02	167	1333	----	----	

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Figure 9. Graph of Flexural Strength Versus Density

Table 3. Flexural Strengths of Specimens

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu ft)	LOAD (Lb)	STRENGTH (Psi)	STRAIN (%)	MODULUS (Psi x 10 ⁵)	TEST TEMP.
3B*	91-3	1	22.8914	34.87	25.2	2419	0.20	3.01	Room
		2	22.6428	34.49	22.9	2198	0.18	3.19	
		3	22.5300	34.32	24.8	2380	0.22	2.82	
		4	22.5708	34.38	22.6	2169	0.19	3.01	
		5	22.4780	34.24	30.0	2880	0.28	3.01	
		Avg.	22.6226	34.46	25.1	2409	0.21	3.01	500°F
		6	22.4507	34.20	20.8	1996	0.20	2.27	
		7	22.6405	34.49	22.3	2140	0.22	2.27	
		8	22.7705	34.69	21.7	2083	0.20	2.39	
		9	22.6105	34.44	22.4	2150	0.23	2.27	
4D	91-4	10	22.4085	34.14	20.7	1987	0.20	2.39	Room
		Avg.	22.5761	34.39	21.6	2071	0.21	2.32	
		6	23.6066	35.95	27.2	2611	0.23	3.19	
		7	23.1889	35.33	24.0	2304	0.21	3.01	
		8	23.6015	35.95	26.0	2496	0.21	3.19	
		9	23.1405	35.25	23.5	2256	0.19	3.19	500°F
		10	23.5368	35.86	26.5	2544	0.22	3.19	
		Avg.	23.4149	35.67	25.4	2442	0.21	3.15	
		6	23.0754	35.15	17.1	1641	0.16	2.39	
		7	23.3459	35.56	22.0	2112	0.22	2.39	
2A**	91-2	8	23.2065	35.35	19.5	1872	0.18	2.39	Room
		9	23.4681	35.75	22.8	2188	0.22	2.39	
		10	23.2878	35.48	17.8	1708	0.16	2.39	
		Avg.	23.2767	35.46	19.8	1904	0.19	2.39	
		1	22.9787	35.01	32.0	3072	0.22	3.39	500°F
		2	23.0343	35.09	29.0	2784	0.20	3.39	
		3	23.1340	35.24	31.0	2976	0.22	3.64	
		4	23.2685	35.45	29.7	2851	0.20	3.64	
		5	23.1120	35.21	29.2	2803	0.20	3.39	
4C	91-4	Avg.	23.1055	35.20	30.2	2897	0.21	3.49	Room
		6	23.1335	35.24	26.8	2572	0.22	2.72	
		7	22.9765	35.00	25.7	2465	0.22	2.56	
		8	23.0275	35.08	25.2	2410	0.21	2.72	
		9	23.3025	35.50	26.2	2515	0.22	2.72	500°F
		10	23.0940	35.18	22.9	2198	0.19	2.72	
		Avg.	23.1068	35.20	25.4	2434	0.21	2.69	
		1	22.6238	34.46	21.8	2092	0.19	2.82	
		2	23.1670	35.29	25.4	2438	0.20	3.19	
		3	22.5785	34.40	24.2	2323	0.21	3.01	Room
4C	91-4	4	23.0524	35.12	24.6	2361	0.20	3.19	
		5	22.5210	34.31	22.5	2160	0.20	3.01	
		Avg.	22.7885	34.72	23.7	2275	0.20	3.04	
		6	23.0320	35.09	19.4	1862	0.19	2.27	500°F
		7	22.4148	34.15	18.8	1804	0.19	2.27	
		8	23.1608	35.28	22.3	2140	0.22	2.39	
		9	22.3865	34.10	20.8	1996	0.22	2.15	
		10	23.1518	35.27	23.3	2236	0.22	2.27	
		Avg.	22.8292	34.78	20.9	2008	0.21	2.27	

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Dimensions (40H)

Length (L)	10.00 ± 0.06
Width (W)	0.500 ± 0.005
Thickness (t)	0.500 ± 0.003

Figure 10. Flexural Strength Specimen, ASTM D790-58T
(Dimensions are in Inches.)

Preferred Style Square 120A

Figure 11. Shear Strength Specimen, ASTM D732-46
(Dimensions are in Inches.)

Figure 12. Graph of Shear Strength Versus Density

Table 4. Shear Strengths of Specimens

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu ft)	LOAD (Lb)	STRENGTH (Psi)	STRAIN (%)	MODULUS (Psi x 10 ⁵)	TEST TEMP.
3B*	91-3	1	17.3701	34.37	2100	1337	----	----	Room
		2	18.1671	35.94	1930	1229	----	----	
		3	17.8795	35.37	2100	1337	----	----	
		4	17.4678	34.56	1900	1210	----	----	
		5	18.1272	35.86	2150	1369	----	----	
		Avg.	17.8023	35.22	2036	1296	----	----	500°F
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
4D	91-4	10	17.5802	34.78	1950	1242	----	----	Room
		Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	500°F
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
2A**	91-2	8	17.3088	34.24	1950	1242	----	----	Room
		9	18.2150	36.04	2260	1439	----	----	
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	500°F
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	Room
4C	91-4	6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	500°F
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
		10	17.5802	34.78	1950	1242	----	----	Room
2A**	91-2	Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	500°F
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	
4C	91-4	10	17.5802	34.78	1950	1242	----	----	Room
		Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	
		8	17.3088	34.24	1950	1242	----	----	
		9	18.2150	36.04	2260	1439	----	----	500°F
		10	17.5802	34.78	1950	1242	----	----	
		Avg.	17.6726	34.96	2034	1295	----	----	
		6	17.5840	34.79	1910	1216	----	----	
		7	17.6751	34.97	2100	1337	----	----	

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Figure 13. Graph of Compressive Strength Versus Density (Vertical Direction)

Table 5. Compressive Strengths (Vertical)

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu ft)	LOAD (Lb)	STRENGTH (Psi)	STRAIN (%)	MODULUS (Psi x 10 ⁵)	TEST TEMP.
3B*	91-3	1	2.2720	34.61	630	2520	1.1	2.85	Room
		2	2.2626	34.47	640	2560	1.2	2.66	
		3	2.2642	34.49	640	2560	1.1	2.85	
		4	2.2526	34.32	620	2480	1.0	2.85	
		5	2.2663	34.52	590	2370	1.0	2.66	
		Avg.	2.2635	34.48	620	2500	1.1	2.77	500°F
		6	2.3147	35.26	611	2444	1.4	2.50	
		7	2.2825	34.77	612	2448	1.5	2.50	
		8	2.3105	35.20	613	2452	1.5	2.22	
		9	2.2928	34.93	625	2500	1.5	2.22	
4D	91-4	10	2.2736	34.64	599	2396	1.5	2.22	
		Avg.	2.2948	34.96	612	2448	1.5	2.33	Room
		1	2.4255	36.95	630	2520	1.2	2.85	
		2	2.4311	37.04	630	2520	1.3	2.66	
		3	2.4350	37.09	620	2480	1.1	2.85	
		4	2.4277	36.98	640	2560	1.3	2.85	
		5	2.4261	36.96	600	2400	1.1	2.85	
		Avg.	2.4291	37.00	620	2500	1.2	2.81	500°F
		6	2.4321	37.05	619	2476	1.3	2.50	
		7	2.4277	36.98	620	2480	1.8	2.50	
2A**	91-2	8	2.4274	36.98	581	2324	1.4	2.22	
		9	2.4050	36.64	573	2292	1.4	2.22	
		10	2.4226	36.91	625	2500	1.5	2.50	
		Avg.	2.4230	36.91	604	2414	1.5	2.39	Room
		1	2.2286	33.95	500	2000	1.0	2.85	
		2	2.2125	33.70	520	2080	1.0	2.85	
		3	2.2435	34.18	460	1840	1.0	2.85	
		4	2.2348	34.04	540	2160	1.0	2.85	
		5	2.2477	34.24	630	2520	1.2	2.85	
		Avg.	2.2334	34.02	530	2100	1.0	2.85	500°F
		6	2.1727	33.10	501	2004	1.1	2.22	
		7	2.1973	33.47	532	2128	1.2	2.50	
4C	91-4	8	2.2048	33.59	520	2080	1.0	2.50	
		9	2.1249	32.37	440	1760	0.8	2.50	
		10	2.1509	32.77	440	1760	0.8	2.22	
		Avg.	2.1701	33.06	487	1946	1.0	2.39	Room
		1	2.2934	34.94	590	2360	0.9	2.85	
		2	2.2520	34.31	530	2120	0.9	2.66	
		3	2.2300	33.97	510	2040	0.9	2.50	
		4	2.2625	34.47	540	2160	0.9	2.66	
		5	2.2319	34.00	490	1960	0.9	2.66	
		Avg.	2.2540	34.34	530	2130	0.9	2.67	500°F
		6	2.2831	34.78	500	2000	1.3	2.00	
		7	2.2853	34.81	485	1940	1.3	2.22	
		8	2.2935	34.94	477	1908	1.3	2.00	
		9	2.2607	34.44	490	1960	1.4	2.00	
		10	2.2805	34.74	461	1844	1.2	2.00	
		Avg.	2.2806	34.74	483	1930	1.3	2.04	

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Figure 14. Compressive Strength Specimen, ASTM D695-54
(Dimensions are in Inches.)

Figure 15. Orientation of Fibers in Composite Billets
(Dimensions are in Inches.)

Figure 16. Graph of Compressive Strength Versus Density (Horizontal Direction)

Table 6. Density Correlation (lb/cu ft)

	BILLET DENSITY	TENSILE SPECIMEN	FLEXURAL SPECIMEN	SHEAR SPECIMEN	COMPRESSION HORIZONTAL SPECIMEN	COMPRESSION VERTICAL SPECIMEN
6	38.3 R.T. 500°F	37.7 37.7	38.5 38.1	38.3 38.4	38.2 38.6	38.5 38.4
5	34.7 R.T. 500°F	34.8 34.1	35.8 35.0	34.9 35.0	35.8 35.5	35.5 35.1
1	33.1 R.T. 500°F	33.6 33.5	33.5 33.8	33.4 33.7	33.8 33.7	33.8 33.5
7	34.0 R.T. 500°F	34.1 34.1	34.3 34.4	33.5 34.7	34.6 34.5	34.5 34.6
8	34.6 R.T. 500°F	34.8 34.9	35.0 35.1	34.4 34.9	35.3 35.1	35.4 35.3
2	33.6 R.T. 500°F	34.2 34.1	34.2 34.2	34.4 34.0	34.5 35.1	34.5 34.9
2A	* R.T. 500°F	38.0 37.3	35.2 35.2	34.0 33.9	35.1 33.8	34.0 33.0
3	33.3 R.T. 500°F	33.1 33.0	33.5 33.4	33.3 33.5	33.8 33.7	34.2 33.8
3B	* R.T. 500°F	36.9 36.8	34.5 34.4	35.2 35.0	35.1 35.4	34.5 35.0
4	35.0 R.T. 500°F	34.5 34.7	34.8 34.7	34.8 35.1	35.3 35.1	35.4 35.4
4C	* R.T. 500°F	36.2 36.0	34.7 34.8	33.5 33.4	34.4 34.8	34.3 34.7
4D	* R.T. 500°F	38.2 38.7	35.7 34.5	35.0 33.5	36.3 35.9	37.0 36.9
9	31.7 R.T. 500°F	31.7 32.1	31.8 31.6	31.8 31.6	31.9 31.9	32.0 31.8

*Not available

Table 7. Compressive Strengths (Horizontal)

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu. ft)	LOAD (Lb)	STRENGTH (Psi)	STRAIN (%)	MODULUS (Psi x 10 ⁵)	TEST TEMP.
3B*	91-3	1	2.2875	34.85	760	3040	1.2	4.00	Room
		2	2.3099	35.19	745	2980	1.4	3.33	
		3	2.3677	36.07	755	3020	1.2	3.33	
		4	2.2555	34.36	780	3120	1.4	3.33	
		5	2.3130	35.24	825	3300	1.4	3.33	
		Avg.	2.3067	35.14	773	3092	1.3	3.46	500°F
		6	2.2829	34.78	732	2928	1.6	2.50	
		7	2.3330	35.54	718	2872	1.7	2.50	
		8	2.3245	35.41	732	2928	1.5	2.50	
		9	2.3230	35.39	743	2972	1.6	2.50	
4D	91-4	10	2.3405	35.65	730	2920	1.5	2.50	Room
		Avg.	2.3208	35.35	731	2924	1.6	2.50	
		6	2.4128	36.76	795	3180	1.8	3.33	500°F
		7	2.3587	35.93	732	2928	1.4	3.33	
		8	2.3852	36.34	798	3192	1.5	3.33	
		9	2.3527	35.84	720	2880	1.3	3.33	
		10	2.3960	36.50	805	3220	1.5	3.33	
		Avg.	2.3811	36.27	770	3080	1.5	3.33	Room
		6	2.3380	35.62	712	2848	1.7	2.50	
		7	2.4164	36.81	628	2512	1.2	2.22	
2A*	91-2	8	1.7846	34.85	448	1792	1.5	1.66	
		9	2.4093	36.70	770	3080	1.8	2.50	
		10	2.3439	35.71	695	2780	1.5	2.22	
		Avg.	2.2584	35.94	651	2602	1.5	2.22	500°F
		6	2.2114	33.69	750	3000	1.4	2.85	
		7	2.1977	33.48	750	3000	1.4	2.85	
		8	2.2743	34.65	761	3044	1.4	2.85	
		9	2.2374	34.08	822	3288	1.5	2.85	
		10	2.1645	32.97	645	2580	1.1	2.85	Room
		Avg.	2.2171	33.77	746	2982	1.4	2.85	
4C	91-4	6	2.2114	33.69	750	3000	1.4	2.85	
		7	2.1977	33.48	750	3000	1.4	2.85	
		8	2.2743	34.65	761	3044	1.4	2.85	
		9	2.2374	34.08	822	3288	1.5	2.85	
		10	2.1645	32.97	645	2580	1.1	2.85	
		Avg.	2.2171	33.77	746	2982	1.4	2.85	Room
		1	2.2498	34.27	695	2780	1.3	4.00	
		2	2.2680	34.55	700	2800	1.2	4.00	
		3	2.2398	34.12	695	2780	1.3	2.85	
		4	2.2922	34.92	660	2640	2.0	2.85	
		5	2.2514	34.30	700	2800	1.3	2.85	500°F
		Avg.	2.2602	34.43	690	2760	1.4	3.31	
		6	2.3059	35.13	631	2524	1.4	2.50	
		7	2.2843	34.80	650	2600	1.5	2.50	
		8	2.2667	34.53	622	2488	1.5	2.50	
		9	2.2930	34.93	673	2692	1.6	2.50	Room
		10	2.2562	34.37	675	2700	1.6	2.50	
		Avg.	2.2812	34.75	650	2601	1.5	2.50	

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Figure 17. Deflection (Heat Distortion) Specimen, ASTM D648-56
(Dimensions are in Inches.)

Table 8. Heat Distortions (Tested at 264 psi)

BILLET	LOT	SPECIMEN	WEIGHT (Gm)	DENSITY (Lb/Cu ft)	HDT (°F)
3B*	91-3	1	11.2642	34.32	805
		2	11.2097	34.15	805
		Avg.	11.2370	34.24	805
4D	91-4	1	11.6902	35.62	773
		2	11.4676	34.94	788
		Avg.	11.5789	35.28	781
2A**	91-2	1	11.5816	35.29	790
		2	11.4239	34.81	805
		Avg.	11.5028	35.05	798
4C	91-4	1	11.4519	34.89	790
		2	11.0195	33.57	805
		Avg.	11.2357	34.23	798

* Billets 3B and 4D were molded, machined, and tested at Bendix.

** Billets 2A and 4C were molded at Whittaker and then machined and tested at Bendix.

Figure 18. Graph of Thermal Conductivity Versus Mean Temperature

Figure 19. Thermal Conductivity Specimen, ASTM C177-45
(Dimensions are in Inches.)

Table 9. Thermal Conductivity Measurements

IDENTIFICATION	SPECIMEN	DIA. (In.)	THICKNESS (In.)	WEIGHT (Gm)	DENSITY (Lb/Cu Ft)	ΔT ACROSS SPECIMEN	MEAN TEMP.	K VALUE
89-1	89-1-1-A	8.014	.434	223.45	38.89	53.2	107	.897
		8.016	.433	200.3	35.01			
89-1	89-1-1-B	8.014	.483	243.55	38.10	117.3	288	1.144
		8.004	.482	241.2	37.91			
90-1	90-1-1-A	8.020	.412	185.6	33.97	44.5	102	.776
		8.020	.415	187.1	33.97			
90-1	90-1-1-B	8.022	.413	187.1	34.15	45.3	472	1.041
		8.022	.415	187.5	34.15			
91-1	91-1-1-A	8.008	.471	213.7	34.39	63.5	108	.853
		7.995	.471	210.5	33.91			
91-1	91-1-1-B	8.008	.487	222.0	34.48	50.6	425	1.042
		7.997	.487	219.0	34.11			
91-1	91-1-2-A	8.017	.450	205.75	34.51	55.4	106	.839
		8.000	.450	202.3	34.07			
91-1	91-1-2-B	8.009	.437	199.1	34.61	126.8	286	.954
		7.998	.435	196.6	34.11			
91-1	91-1-3-A	8.006	.471	214.18	34.41	61.4	109	.846
		7.993	.471	211.4	34.08			
91-1	91-1-3-B	8.005	.427	199.3	35.33	122	283	1.077
		7.991	.427	197.1	34.98			
91-2	91-2-1-A	8.015	.503	229.4	34.44	62.6	108	.909
		8.000	.503	224.8	33.87			
91-2	91-2-1-B	8.014	.470	214.7	34.50	50.3	463	1.089
		7.995	.469	210.3	34.06			
91-3	91-3-1-A	8.012	.503	223.2	33.53	59.5	110	.849
		8.000	.503	219.6	33.09			
91-3	91-3-1-B	8.012	.486	213.25	33.16	138.2	296	1.048
		7.996	.485	210.4	32.91			
91-4	91-4-1-A	8.038	.498	236.6	35.67	55.9	111	.833
		8.002	.496	233.0	35.59			
91-4	91-4-1-B	8.028	.506	234.6	35.03	141.8	292	1.040
		8.012	.506	234.6	35.03			
91-4	K-8	8.018	.502	238.06	35.78	49.5	76	.855
		8.022	.501	238.8	35.86			
91-4	K-9	8.022	.501	243.52	36.64	89.2	462	1.193
		8.020	.499	243.5	36.73			
91-3	K-6	8.014	.503	227.24	34.12	47.6	76	.901
		8.000	.502	223.7	33.71			
91-3	K-7	8.018	.503	229.20	34.38	94.1	441	1.139
		8.010	.501	225.9	34.03			

NOTE: Thermal conductivity measurements were made on the Thermal Physics GP-1800 instrument, with estimated accuracy of ± 2 percent. All densities were calculated by weight/volume. All specimens were tested at BKC: only billets K6, K7, K8, K9 were molded and tested at BKC. Refer to Table 1 for batch identification of specimens.

Appendix A

BKC DRAWING 2144060

		DWG CLASSIFICATION LEVEL		2144060			
DESIGN AGENCY CONTROL NO.	REVISIONS					MATL. ENGR	SPEC ENGR
	ISSUE	DESCRIPTION	PREPARED BY	DATE			
00	A	<i>D.D.S.</i> D. D. Smith <i>Released 1-22-69 mg</i>		1-22-69	<i>PRK</i>	<i>PRK</i>	
01	B	ECN 7153128 Revised extensively. <i>D.D.S.</i> D. D. Smith <i>Released 8-18-61 AT</i>		8-18-69	<i>PRK</i>	<i>PRK</i>	
Drawing Call-Out: Syntactic Foam, Molding Powder /per 2144060-01.							
SHEET	SHEET						
	ISSUE						
INDEX	SHEET	1	2	3	4	5	6
	ISSUE	B	B	B	B	B	B
AGENCY APPROVALS				TITLE			
ORG	DATE	INITIALS		MOLDING COMPOUND, SYNTACTIC FOAM, GLASS MICROBALLOON FILLED			
BX	6-69	WJE					
LS	6-69	LMS					
DWG CLASSIFICATION LEVEL				SIZE	CODE IDENT	DWG NUMBER	
UNCLASSIFIED				A	14214	2144060	
				SHEET		OF	
				1		7	

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BX-SP8300 - A (8-67)

-BX/BX-----U-N-C-L-A-S-S-I-F-I-E-D-----

PART OR CONTROL NO	DESCRIPTION	LINE NO
	2. DOCUMENTS	02500
	2.1. REQUIRED	02600
ASTM-D-638-64T	TESTING, TENSILE PROPERTIES OF PLASTICS	02700 RT081
ASTM-D-695-63T	TESTING, COMPRESSIVE PROPERTIES OF RIGID PLASTICS	02800 RT081
ASTM-D-732-46	TESTING, SHEAR STRENGTH, PLASTICS	02900
ASTM-D-790-66	FLEXURAL PROPERTIES OF PLASTICS	03000
ASTM-D-1622-63	TESTING, APPARENT DENSITY, RIGID CELLULAR PLASTICS	03100 RT081
ASTM-C-177-63	THERMAL CONDUCTIVITY OF MATERIALS BY MEANS OF THE GUARDED HOT PLATE	03200 RT081

CODE IDENT---14214
DATE---06/16/69

DRAWING NUMBER---2144060
CONTROL SUFFIX---01 ISSUE--- B

-BX/BX-----U-N-C-L-A-S-S-I-F-I-E-D-----SHEET--- 2 OF

	DWG CLASSIFICATION LEVEL																										
<p>1. <u>GENERAL.</u></p> <p>1.1 <u>Scope.</u> This specification covers the requirements of a syntactic foam molding powder consisting of a thermally stable heteromatic resin filled with microballoons and fibrous filler.</p> <p>2. <u>DOCUMENTS.</u></p> <p>See Sheet 2.</p> <p>3. <u>REQUIREMENTS.</u></p> <p>3.1 <u>Procurement Source.</u> The material shall be the following:</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <u>Material Producer's</u> <u>or Supplier's</u> <u>Product Designation</u> </td> <td style="width: 50%; vertical-align: top;"> <u>Material Producer</u> <u>or</u> <u>Authorized Supplier</u> </td> </tr> <tr> <td style="text-align: center;">Imidite SA</td> <td style="text-align: center;">Whittaker Corporation</td> </tr> </table> <p>3.2 The color of the powdered raw material when visually inspected shall be tan.</p> <p>3.3 The material shall meet the following requirements:</p> <table style="width: 100%; border: none;"> <thead> <tr> <th style="text-align: left;"><u>Property</u></th> <th style="text-align: left;"><u>Requirements</u></th> <th style="text-align: left;"><u>Test Method</u></th> </tr> </thead> <tbody> <tr> <td>a. Density</td> <td>31.5-38.5 lbs/ft³</td> <td>4.5.2.1</td> </tr> <tr> <td>b. Thermal Conductivity @ 500°F</td> <td>1.3 BTU-in. hr -ft² -°F Max</td> <td>4.5.2.2</td> </tr> <tr> <td>c. Compression Strength (Horizontal) @ 500°F</td> <td>2400 psi, min</td> <td>4.5.2.3</td> </tr> <tr> <td>d. Tensile Strength @ 500°F</td> <td>750 psi, min</td> <td>4.5.2.4</td> </tr> <tr> <td>e. Shear Strength @ 500°F</td> <td>900 psi, min</td> <td>4.5.2.5</td> </tr> <tr> <td>f. Flexural Strength @ 500°F</td> <td>1000 psi, min</td> <td>4.5.2.6</td> </tr> </tbody> </table> <p>4. <u>QUALITY ASSURANCE PROVISIONS.</u></p> <p>4.1 <u>Lot Definition and Identification.</u> A homogeneous unit of material A lot shall be that quantity of material offered for acceptance at one time, which was produced in one manufacturing cycle under one set of conditions or produced in more than one manufacturing cycle under similar conditions and subsequently combined and thoroughly blended. The lot shall be identified by a method that is compatible with the lot definition.</p>			<u>Material Producer's</u> <u>or Supplier's</u> <u>Product Designation</u>	<u>Material Producer</u> <u>or</u> <u>Authorized Supplier</u>	Imidite SA	Whittaker Corporation	<u>Property</u>	<u>Requirements</u>	<u>Test Method</u>	a. Density	31.5-38.5 lbs/ft ³	4.5.2.1	b. Thermal Conductivity @ 500°F	1.3 BTU-in. hr -ft ² -°F Max	4.5.2.2	c. Compression Strength (Horizontal) @ 500°F	2400 psi, min	4.5.2.3	d. Tensile Strength @ 500°F	750 psi, min	4.5.2.4	e. Shear Strength @ 500°F	900 psi, min	4.5.2.5	f. Flexural Strength @ 500°F	1000 psi, min	4.5.2.6
<u>Material Producer's</u> <u>or Supplier's</u> <u>Product Designation</u>	<u>Material Producer</u> <u>or</u> <u>Authorized Supplier</u>																										
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f. Flexural Strength @ 500°F	1000 psi, min	4.5.2.6																									
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">ISSUE</td> <td style="width: 10%;">B</td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>	ISSUE	B															DWG CLASSIFICATION LEVEL UNCLASSIFIED	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">SIZE</td> <td style="width: 10%;">CODE IDENT</td> <td style="width: 80%;">DWG NUMBER</td> </tr> <tr> <td style="text-align: center;">A</td> <td style="text-align: center;">14214</td> <td style="text-align: center;">2144060</td> </tr> <tr> <td colspan="2"></td> <td style="text-align: center;">SHEET 3 OF</td> </tr> </table>	SIZE	CODE IDENT	DWG NUMBER	A	14214	2144060			SHEET 3 OF
ISSUE	B																										
SIZE	CODE IDENT	DWG NUMBER																									
A	14214	2144060																									
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BX. SP5300-AA (5-67)

DWG CLASSIFICATION LEVEL

4.5.1.2 Procedure.

- a. Mold release all sections of the mold. It is desirable to bake mold release.
- b. Weigh the required quantity of molding powder and pack to a uniform depth.
- c. A thin plate which fits into the frame can be placed over the material. If a plunger is used it is then placed over the plate.

NOTE: For large billets it has been desirable to drill several holes in the thin plate and then place glass cloth between plate and plunger.

- d. Place 3-4 layers of glass cloth around the mold assembly. This is to prevent the vacuum bag from tearing.
- e. The covered mold is placed within a vacuum bag or on a vacuum plate assembly and then the bag material is sealed.
- f. The assembly is placed into a forced connection oven and vacuum applied. The vacuum shall be maintained at 0.5 to 5 mm Hg during the cure cycle.
- g. The oven is turned on and the cycle controlled as follows:
 - 30 minutes $\pm$ 10 minutes @250 $\pm$ 10°F
 - 40 minutes $\pm$ 10 minutes @300 $\pm$ 10°F
 - 60 minutes $\pm$ 15 minutes @350 $\pm$ 15°F
 - 60 minutes $\pm$ 15 minutes @400 $\pm$ 15°F
 - 60 minutes $\pm$ 15 minutes @450 $\pm$ 20°F
 - 60 minutes $\pm$ 15 minutes @500 $\pm$ 20°F
 - 60 minutes $\pm$ 15 minutes @550 $\pm$ 20°F
 - 30 minutes $\pm$ 10 minutes @600 $\pm$ 20°F

Total 6 hours 40 minutes $\pm$ 40 minutes.

- h. Test blocks are placed in a steel retort fitted with lid and adequate tubing for preheating the argon gas. The argon should be at the oven temperature before entering the retort.
- i. The retort is purged continuously during the post cure cycle and while cooling.

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5. PACKAGING, HANDLING, AND STORAGE.

5.1 Protective Packaging. The material shall be packaged in a moisture proof bag in order to prevent contamination from moisture. Packaging container must prevent unnecessary exposure to light. More than one bag can be packaged in a container.

5.2 Package or Container Identification. Each individual bag and container of material shall be marked with the following information:

Material Specification Number
Product Designation
Name of Material Producer
Material Producer's Lot Number
Date of Shipment
Shelf Life: 3 months from date of shipment

5.3 Safety and Material Damage Precautions. This material will darken when exposed to moisture or light. Adequate precautions should be exercised in handling.

5.4 Storage and Use Limitations. If the container of material is opened it should be purged with argon and sealed before storage. If the color of the powdered material turns black it shall be discarded.

5.4.1 Shelf Life. The shelf life is 3 months from the date of shipment when stored at 50-100°F. Any material that exceeds this shelf life shall be reinspected to the requirements of section 4.3. If it meets the requirements, the shelf life may be extended an additional three months. If it fails to meet any requirement, the material shall be discarded. Shelf life may be extended for three month intervals by retesting until the material is either consumed or discarded.

6. NOTES.

NOT APPLICABLE.

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BX. 875300-AA (5-67)

Appendix B

WHITTAKER CORPORATION DEVELOPMENT REPORT
(24 June 1969)

DEVELOPMENT OF IMIDITE SA FOAM TEST AND
MATERIAL SPECIFICATIONS

FINAL REPORT

24 June 1969

By
Alfred H. McLeod
WHITTAKER CORPORATION
Research & Development/San Diego
3540 Aero Court
San Diego, California 92123

Contract No. D688346
The Bendix Corporation
Kansas City Division
Kansas City, Mo. 64141

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INTRODUCTION

Polybenzimidazole syntactic foams were developed as low density ablative heat shield materials by Whittaker Research & Development/San Diego (WRD) under contract to NASA*. WRD later marketed two of the better formulations under the trade names of IMIDITE SA and IMIDITE PC foam compounds. The IMIDITE PC, which contains phenolic microballoons and carbon fibers in addition to the polybenzimidazole resin, is intended for ablative purposes where high carbon char is required. The IMIDITE SA versions, which contains silica microballoons and alumina-silica fibers along with the polybenzimidazole prepolymer, is intended for general purpose use when high strength and heat resistance are required.

And, inasmuch as these foams were developed under government contracts, the amount of test data pertaining to the materials is limited. This contract was initiated to obtain sufficient test data to prepare material specifications around IMIDITE SA powder and to obtain needed mechanical test data.

*"Study for Development of Improved Char Forming Heat Shield" Contract NAS7-340; Ames Research Center, Mountain View, Calif., Nov 1965

TECHNICAL DISCUSSION

This program was originated to study the mechanical, physical and chemical properties of IMIDITE SA foam. These materials are based on a polybenzimidazole resin (IMIDITE 2801), silica microballoons and a ceramic fiber. When properly cured, these result in a strong, heat-resistant syntactic foam.

The IMIDITE SA foam is made by curing the IMIDITE SA powder with heat and pressure, followed by a postcure. During postcure, the material reaches a peak temperature of 850°F. The resulting foam, depending upon the cure cycle employed, will have a density between 25 and 40 lb/ft³.

The objectives of the program are threefold:

1. Obtain data from which to prepare a materials specification for IMIDITE SA powder.
2. Obtain mechanical test data for engineering design purposes.
3. Obtain sufficient data for WRD to certify the properties of the IMIDITE SA powder.

The general program plan has been to study seven batches of IMIDITE SA powder prepared from four batches of IMIDITE 2801 prepolymer. These seven batches of IMIDITE SA powder were used to produce nine pairs of billets for mechanical tests. One additional billet was used to study the effect of the cure cycle. In addition, 2 billets and 2 lots of foam were to be delivered to Bendix-K.C. Figure 1 shows a materials scheme for these batches of material and billets.

The 9 pairs of billets, discussed above, were cut into specimens for mechanical testing. In each case, the smaller billet was cut into a pair of thermal-conductivity specimens which were forwarded to Bendix-K.C. for testing. The larger billets were cut up into specimens for mechanical testing of tensile, shear, compression, flexure and heat-distortion temperature. Samples were also prepared for isothermal weight loss, burnout, and water adsorption studies.

A summary of test results obtained from these billets is shown in Tables 1 through 6. Raw data is presented in Appendix A and the correlation (coefficient) between the test is shown in Appendix B.

Table 1 shows physical properties of the 9 billets studied. Table 2 (computer print out) compares the raw average of mechanical properties for billets 1 through 9 with an average corrected to a density of 34 lb/ft³. This correction was based on a least squares line through all of the data obtained for the test. This table also shows the standard deviation of each 5 specimens around the billet mean. The average standard deviation is actually an average of the square of the standard deviation (mean variance) and, therefore, is a root-mean-square value. This procedure has been followed in each case when an average standard deviation is presented in this report.

Figure 1. General Materials Scheme

TABLE 1
PROPERTIES OF IMIDITE SA FOAM

Billet Number	1	7	8	2	3	4	5	6	9	Average	RMS Std Dev Around Sample Mean	Number of Specimens Tested
IMIDITE 2801 Prepolymer, Batch	91	91	91	91	91	91	90	89	92			
IMIDITE SA Foam, Batch	91-1	91-1	91-1	91-2	91-3	91-4	90-1	89-1	92-1			
Billet Density lb/ft ³	33.1	34.0	34.5	33.6	33.3	35.0	34.7	38.3	31.7	34.3	--	1
Heat Distortion Temp 264 psi, °F	788	771?	794	780	794	770	732	768	711	768	14.6	2
Heat Distortion Temp 66 psi, °F	896	902	898	926	965	919	852	846	764	885	12.8	2
Weight Loss after 60 hr at 650°F, %	11.85	15.06	11.28	12.72?	13.45	13.94	16.41	13.69	13.98*	13.71	--	3
Weight Loss after 20 hr at 1150°F, %	57.26	57.36	58.62	57.42	58.27	57.33	57.27	56.10	56.28	57.32	0.29	3
Water Pickup (1 hr water boil) % Vol	40.8	41.6	40.3	38.7	40.2	50.2	42.5	49.5	35.8	42.2	0.47	3
Wt Loss after 1 hr water boil and dry, %	0.85	0.99	0.55	0.87	0.72	0.97	1.32	0.97	0.83	0.90	--	3
Thermal Conductivity at RT												
Thermal Conductivity at 500°F												

* Test not directly comparable with other data.

TABLE 2

CORRECTED AND UNCORRECTED MECHANICAL TEST DATA

BLT	RAW AVG	CORR AVG	EXCHANGE	STD DEV	SPEC
TENSILE STRENGTH					
			70		
1	1468	1575	5.83	76.7	5
2	1542	1581	8.5	337.3	5
3	1484	1491	4.74	110.7	5
4	1445	1349	-6.67	115.8	5
5	1437	1370	-4.69	326.2	5
6	1521	1107	-87.83	123.8	5
7	1714	1714	0	86	5
8	1695	1637	-3.41	125.8	5
9	895	1117	84.76	228.2	5
AVG	1462	1438	8.87	195.035	
SHEAR STRENGTH					
			70		
1	1614	1677	3.89	16.3	5
2	1735	1763	1.61	47.9	5
3	1632	1681	2.99	57.8	5
4	1552	1482	-4.5	101.4	5
5	1369	1320	-3.57	193.1	5
6	1852	1552	-16.8	203.1	5
7	1570	1570	0	127.2	5
8	1638	1596	-2.56	130.2	5
9	1325	1486	12.11	197.5	5
AVG	1587	1570	5.27	136.161	
FLEXURE STRENGTH					
			70		
1	2719	2845	4.63	49.7	5
2	2976	3032	1.88	118	5
3	2942	3080	3.28	342	5
4	2264	2144	-6.13	364	5
5	2498	2400	-3.92	519.9	5
6	3007	2405	-20.010	485.1	5
7	2935	2935	0	127.7	5
8	3031	2947	-2.77	88	5
9	1823	2145	17.65	566.4	5
AVG	2695	2659	6.7	352.189	
FLEXURE MODULUS X10 ⁵					
			70		
1	2.95	2.29	-1.94	0.14	5
2	3.14	3.11	-0.81	0.14	5
3	3.11	3.07	-1.43	0.11	5
4	2.04	2.1	3.12	0.36	5
5	2.01	2.05	2.22	0.4	5
6	2.68	2.95	10.23	0.56	5
7	3.11	3.11	0	0.19	5
8	3.09	3.13	1.24	0.18	5
9	3.02	2.87	-4.85	0.07	5
AVG	2.79	2.81	2.87	0.28439	
COMPRES STR., VERT					
			70		
1	3039	3171	4.34	158.4	5
2	3126	3185	1.87	223.7	5
3	3300	3403	3.11	137	5
4	3346	3199	-4.38	246	5
5	2911	2808	-3.52	212.4	5
6	3697	3067	-17.04	384	5
7	2782	2782	0	447.5	5
8	3028	2940	-2.9	148.3	5
9	2718	3055	12.4	172.5	5
AVG	3105	3068	5.51	257.982	
COMPRES STR., HORZ					
			70		
1	3591	3777	5.19	302.4	5
2	3695	3778	2.24	256.6	5
3	3897	4042	3.72	82	5
4	4060	3853	-5.1	141.4	5
5	3772	3687	-3.84	718.7	5
6	4669	3779	-19.06	288.6	5
7	3605	3605	0	391.5	5
8	3678	3554	-3.38	282.9	5
9	3346	3822	14.23	236.4	5
AVG	3813	3760	6.31	345.888	
COMPRES MOD., VERT X10 ⁵					
			70		
1	2.89	2.93	1.32	0.1	5
2	3.06	3.08	0.64	0.07	5
3	2.98	3.01	1.15	0.06	5
4	2.83	2.78	-1.72	0.07	5
5	2.69	2.86	1.87	0.22	5
6	3.17	2.96	-6.62	0.23	5
7	3.1	3.1	0	0.12	5
8	3.15	3.12	-0.93	0.87	5
9	2.8	2.91	4.01	0.12	5
AVG	2.96	2.95	1.98	0.158605	
COMPRES MOD., HORZ X10 ⁵					
			70		
1	3.4	3.49	2.68	0.17	5
2	3.5	3.54	1.16	0.19	5
3	3.39	3.46	2.09	0.04	5
4	3.26	3.16	-3.1	0.05	5
5	3.67	3.6	-1.93	0.34	5
6	3.66	3.23	-11.88	0.12	5
7	3.97	3.97	0	0.37	5
8	3.58	3.52	-1.69	0.32	5
9	2.98	3.21	7.61	0.24	5
AVG	3.49	3.46	3.59	0.234758	

(continued on next page)

TABLE 2 (Continued)

TENSILE STRENGTH			500		
1	1403	1474	5.03	80.4	5
2	1480	1511	2.12	50.4	5
3	1347	1402	4.07	116.3	5
4	1309	1231	-5.99	150.9	5
5	961	906	-5.71	86.6	5
6	1389	1058	-84.26	313.7	5
7	1496	1496	0	73.8	5
8	1550	1503	-3.03	75.2	5
9	718	898	85.1	151.9	5
AVG	1295	1275	8.37	143.52	
SHEAR STRENGTH			500		
1	1243	1292	3.93	94.6	5
2	1037	1059	2.09	203.1	5
3	1036	1074	3.67	53.1	5
4	1305	1251	-4.16	139.9	5
5	1153	1115	-3.29	250.7	5
6	1280	1047	-18.22	58.9	5
7	1188	1188	0	180.8	5
8	1132	1099	-2.88	90.7	5
9	929	1054	13.43	192.7	5
AVG	1145	1131	5.74	155.263	
FLEXURE STRENGTH			500		
1	2389	2534	6.06	221.1	5
2	2421	2485	2.66	112.3	5
3	2250	2363	5	87.1	5
4	1792	1631	-8.98	238.6	5
5	2056	1943	-5.48	254.2	5
6	2368	1676	-29.21	266.9	5
7	2581	2581	0	169.2	5
8	2620	2523	-3.68	6.8	5
9	1050	1420	35.23	88.3	5
AVG	2170	2129	10.7	182.068	
FLEXURE MODULUS X10 ⁵			500		
1	2.37	2.28	-3.72	0.09	5
2	2.51	2.47	-1.56	0.1	5
3	2.57	2.5	-2.67	0.1	5
4	1.52	1.62	6.44	0.29	5
5	1.8	1.87	3.81	0.07	5
6	1.85	2.27	22.76	0.4	5
7	2.58	2.58	0	0.11	5
8	2.45	2.51	2.4	0.07	5
9	2.45	2.22	-9.19	0.08	5
AVG	2.23	2.26	5.84	0.182726	
COMPRES STR.. VERT			500		
1	2481	2553	2.89	140.9	5
2	2616	2648	1.22	85.4	5
3	2576	2632	2.17	81.7	5
4	2594	2514	-3.08	181.2	5
5	2590	2534	-2.16	122.6	5
6	2742	2399	-12.51	152.8	5
7	2386	2386	0	60.3	5
8	2578	2530	-1.86	173.3	5
9	2178	2362	8.43	361	5
AVG	2527	2506	3.81	172.891	
COMPRES STR.. HORZ			500		
1	2852	3004	5.33	223.3	5
2	3151	3219	2.14	87.8	5
3	2855	2973	4.14	198.6	5
4	3118	2949	-5.42	324	5
5	3099	2981	-3.81	706.8	5
6	3720	3002	-19.48	331.9	5
7	2790	2790	0	340.7	5
8	3078	2977	-3.29	179.2	5
9	2793	3181	13.91	228.9	5
AVG	3052	3008	6.39	335.39	
COMPRES MOD.. VERT X10 ⁵			500		
1	1.49	1.51	1.12	0.03	5
2	1.57	1.58	0.47	0.02	5
3	1.57	1.58	0.82	0.06	5
4	1.62	1.6	-1.14	0.05	5
5	1.53	1.52	-0.85	0.08	5
6	1.6	1.52	-4.97	0.03	5
7	1.5	1.5	0	0.04	5
8	1.59	1.58	-0.7	0.09	5
9	1.5	1.54	2.83	0.24	5
AVG	1.55	1.55	1.43	0.54521E-2	
COMPRES MOD.. HORZ X10 ⁵			500		
1	1.59	1.62	2.01	0.15	5
2	1.79	1.6	0.79	0.06	5
3	1.77	1.79	1.41	0.08	5
4	1.76	1.78	-2.02	0.13	5
5	1.83	1.81	-1.36	0.23	5
6	1.92	1.77	-7.96	0.08	5
7	1.78	1.78	0	0.13	5
8	1.86	1.84	-1.15	0.06	5
9	1.8	1.88	4.54	0.11	5
AVG	1.79	1.78	2.36	0.1853	

TABLE 3

GROUP MEANS OF DATA CORRECTED TO 34 LBS/F° DENSITY

	TEMP	BATCH 91-1	BATCHES 91-1 TO 4	BATCHES 89-92
Tensile Strength	70	1641.97	1569.79	1450.92
Shear Strength	70	1614.31	1626.17	1575.27
Flexure Strength	70	2908.99	2841.71	2677.49
Flexure Modulus $\times 10^5$	70	3.04363	2.92259	2.82192
Compres Str., Vert	70	2964.32	3091.99	3070.2
Compres Str., Horz	70	3645.36	3750.59	3758.76
Compres Mod., Vert $\times 10^5$	70	3.05155	3.01158	2.95693
Compres Mod., Horz $\times 10^5$	70	3.66011	3.54294	3.47203
Tensile Strength	500	1490.84	1443.88	1291.67
Shear Strength	500	1193.09	1165.11	1134.33
Flexure Strength	500	2546.09	2380.49	2153.75
Flexure Modulus $\times 10^5$	500	2.45688	2.34539	2.26706
Compres Str., Vert	500	2489.65	2536.08	2509.35
Compres Str., Horz	500	2923.55	2976.44	3005.2
Compres Mod., Vert $\times 10^5$	500	1.52852	1.5537	1.54812
Compres Mod., Horz $\times 10^5$	500	1.74689	1.75873	1.7777

Note: This table, and many of the following tables, are copies of computer print outs, showing an excessive number of significant digits and lacking trailing zeros.

TABLE 4

GROUP MEANS OF UNCORRECTED DATA

	TEMP	BATCH 91-1	BATCHES 91-1 TO 4	BATCHES 89-92
Tensile Strength	70	1632.33	1562.9	1472.39
Shear Strength	70	1607.33	1621.19	1590.82
Flexure Strength	70	2895	2831.71	2708.67
Flexure Modulus $\times 10^5$	70	3.05	2.92714	2.80771
Compres Str., Vert	70	2949.67	3081.52	3102.85
Compres Str., Horz	70	3624.67	3735.81	3804.88
Compres Mod., Vert $\times 10^5$	70	3.04667	3.0081	2.96781
Compres Mod., Horz $\times 10^5$	70	3.65	3.53571	3.49457
Tensile Strength	500	1483	1438.29	1309.13
Shear Strength	500	1187.67	1161.24	1146.42
Flexure Strength	500	2530	2369	2189.6
Flexure Modulus $\times 10^5$	500	2.46667	2.35238	2.24524
Compres Str., Vert	500	2481.67	2530.38	2527.14
Compres Str., Horz	500	2906.67	2964.38	3042.84
Compres Mod., Vert $\times 10^5$	500	1.52667	1.55238	1.55224
Compres Mod., Horz $\times 10^5$	500	1.74333	1.75619	1.78562

TABLE 5

STANDARD DEVIATION OF DATA CORRECTED TO 34 LB/F³ DENSITY

	Temp	S1	S2	S3	S4
Tensile Strength	70	195	69.8	119.5	211
Shear Strength	70	136.2	55.7	90.5	125.6
Flexure Strength	70	352	55.8	317	365
Flexure Modulus x 10 ⁵	70	0.284	0.1311	0.37	0.403
Compres Str, Vert	70	258	195.6	207	188.5
Compres Str, Horz	70	345	117.1	167.2	140.3
Compres Mod, Vert x 10 ⁵	70	0.1586	0.1024	0.1191	0.1463
Compres Mod, Horz x 10 ⁵	70	0.235	0.269	0.243	0.236
Tensile Strength	500	143.5	15.4	100.9	251
Shear Strength	500	155.3	96.3	90	86.5
Flexure Strength	500	182.1	30.7	338	441
Flexure Modulus x 10 ⁵	500	0.1827	0.1557	0.334	0.306
Compres Str, Vert	500	172.9	90.5	88.7	98.4
Compres Str, Vert	500	335	116.5	127.6	119.9
Compres Mod, Vert x 10 ⁵	500	0.0955	0.0438	0.041	0.036
Compres Mod, Horz x 10 ⁵	500	0.1253	0.1121	0.071	0.0698

Note: S1 is Root Mean Square Standard Deviation of individual specimens around their sample mean. N = 5

S2 is Standard Deviation of averages of Billets 1, 7 and 8 (billets from Batch 91-1) around their mean. N = 3

S3 is Standard Deviation of averages of Batch 91-1 billets with Billets 2, 3 and 4 (billets from Batch 91 IMIDITE 2801 prepolymer) around their mean. N = 4

S4 is Standard Deviation of averages of billets from Batch 91 IMIDITE 2801 prepolymer with Billets 5, 6 and 9 (4 batches of IMIDITE 2801 prepolymer) around their mean. N = 4

TABLE 6

STANDARD DEVIATIONS OF UNCORRECTED DATA

	Temp	S1	S2	S3	S4
Tensile Strength	70	195	125.4	118.6	226
Shear Strength	70	136.2	34.5	59.2	155
Flexure Strength	70	352	159.8	262	396
Flexure Modulus x 10 ⁵	70	0.284	0.0872	0.396	0.434
Compres Str, Vert	70	258	145.3	196.4	289
Compres Str, Horz	70	345	46.7	176.3	358
Compres Mod, Vert x 10 ⁵	70	0.1586	0.138	0.1149	0.1606
Compres Mod, Horz x 10 ⁵	70	0.235	0.291	0.231	0.265
Tensile Strength	500	143.5	74.4	87.4	264
Shear Strength	500	155.3	55.5	100.6	118.3
Flexure Strength	500	182.1	123.7	284	468
Flexure Modulus x 10 ⁵	500	0.1827	0.106	0.374	0.377
Compres Str, Vert	500	172.9	96	83.1	153.3
Compres Str, Horz	500	335	151.6	147	278
Compres Mod, Vert x 10 ⁵	500	0.0955	0.0551	0.0481	0.0457
Compres Mod, Horz x 10 ⁵	500	0.1253	0.1387	0.0821	0.0855

Note: See Table 5 for explanation of symbols.

Tables 3, 4, 5, and 6 show averages and standard deviation for both the corrected and uncorrected data, grouped by IMIDITE SA powder and IMIDITE 2801 batches.

There are three interrelated factors which affect the properties of IMIDITE SA foam. These are: the quality of the IMIDITE SA powder, the density of the cured foam, and the cure cycle used. Because we are interested in evaluating the quality of the IMIDITE SA powder, it is important to have an idea as to the effect of the other two variables on the properties of the cured foam.

EFFECT OF CURE CYCLE

A WRD-sponsored study has shown that the standard cure cycle used to cure billets 1 through 9 does not result in optimum properties to the cured foam. While an optimum cure cycle was not established, mechanical properties are significantly improved if the postcure cycle at 850°F is extended to 16 hours.

Original indications that the standard cure cycle was not adequate included variations in color of cured foam from the same batch and test values which were lower than anticipated. These billets were appreciably larger than the original billets studied at WRD, and as a result, heat transfer in the material may have caused problems.

To test the theory that the cure cycle was not adequate, WRD prepared and tested Billet 11 at company expense. This billet received the standard cure, with the exception that the 850°F postcure time was extended to 16 hours instead of only a brief contact at this temperature.

Table 7 compares the properties of foam from Billet 11 and the average of specimens obtained from Billets 1 through 9. The data shows significant improvement in mechanical properties, in addition to a generally lower standard deviation.

Since an incomplete cure was used to obtain the bulk of the data in this report, the properties of the foam will be greatly effected by minor variations in cure. Presumably, the fully-cured polymer will have more uniform properties than a metastable condition of partial cure. This large variation in foam properties, due to cure cycle, greatly reduces the amount of information which can be obtained from the data by statistical means.

TABLE 7

COMPARISON OF PROPERTIES OF IMIDITE SA FOAM CURED WITH
THE STANDARD CURE CYCLE AND THE EXTEND CURE CYCLE

	Property Value			Standard Deviation		
	Standard Cure Billets 1 to 9	Extended Cure Billet 11	% Change	Standard Cure Billets 1 to 9*	Extended Cure Billet 11	% Change
Density	34.3	34.1	--	--	--	--
Wt Loss after 20 hr at 1150°F, %	57.32	57.07	--	0.29	0.97	234
Water Pickup, % (vol)	42.2	40.3	-4.5	0.47	0.53	13
Heat Distortion Temp (264 psi), °F	768	832	8.3	14.64	11.31	-23
Heat Distortion Temp (66 psi), °F	885	1036	17	12.84	5.65	-55
Hardness (Shore D)	62	66	6.5	--	--	--
RT Tensile Strength	1463	2004	37	195	276	42
RT Tensile Modulus x 10 ⁵	3.05**	3.10**	--	--	--	--
RT Shear Strength	1584	1918	21	136	350	157
RT Flexure Strength	2693	3240	20	352	203	-42
RT Flexure Modulus x 10 ⁵	2.79	3.49	25	0.28	0.04	-85
RT Compressive Strength, Vert	3105	3558	15	258	253	-1.9
RT Compressive Strength, Horiz	3812	4308	13	345	219	-37
RT Compressive Modulus x 10 ⁵ , Vert	2.96	3.19	7.8	0.16	0.11	-31
RT Compressive Modulus x 10 ⁵ , Horiz	3.49	3.70	6.0	0.24	0.08	-67
500°F Tensile Strength	1308	1876	43	144	101	-30
500°F Shear Strength	1145	1700	48	155	66.7	-57

(continued on next page)

TABLE 7 (Continued)

	Property Value			Standard Deviation		
	Standard Cure Billets 1 to 9	Extended Cure Billet 11	% Change	Standard Cure Billets 1 to 9*	Extended Cure Billet 11	% Change
500°F Flexure Strength	2170	2870	32	182	94.8	-48
500°F Flexure Modulus $\times 10^5$	2.23	2.82	26	0.18	0.06	-67
500°F Compressive Strength, Vert	2527	3202	27	173	134	-23
500°F Compressive Strength, Horz	3052	3783	24	335	224	-33
500°F Compressive Modulus $\times 10^5$, Vert	1.55	1.84	19	0.10	0.06	-40
500°F Compressive Modulus $\times 10^5$, Horz	1.79	2.06	15	0.13	0.09	-31

* RMS avg of billet standard deviation 2 to 5 specimens per billet

**Single specimen per billet

EFFECT OF DENSITY

The relationship between various physical properties and density has been determined, using a least-squares linear relationship. The values of the constants for the equation

$$\text{property} = (M)(D) + B$$

where D = Density in lb/ft³

are given in Table 8, along with the value of 100R² which is the percent of the data variance which can be attributed to density. Using these correction factors, the effect of re-evaluating the data has been presented previously. The data in the table show that the best correlation (69%) is obtained between water pickup (void content) and density; indicating that high void content gives high density. This is the opposite of what would be expected, and indicates the great care that must be exercised in interpreting the data. This will be discussed in more detail later in the report.

Another interesting observation is that density appears to be related to the IMIDITE 2801 batch, but there is insufficient data to make a definite conclusion. Should there be a relationship of density to the IMIDITE 2801 batch, it would be the result of random variation between batches, elapsed time since manufacture, or "color of the prepolymer."

ANALYSIS OF MECHANICAL PROPERTIES OF IMIDITE SA FOAM

It would be desirable to select one or two tests to be run instead of testing all of the mechanical properties of each new batch of IMIDITE SA powder to determine if it meets minimum standards for quality. The quality of the material could then be judged on the basis of these tests. If a lesser number of tests are run, it is important that they are a true measure of material quality and not a measure of some meaningless variable.

In selecting the proper tests, there are numerous factors to consider. First, it is important to have a high degree of confidence in individual test values. This confidence is achieved through a narrow spread in test results or, more properly, a small standard deviation relative to the size of the mean. Tables 9 and 10 present the RMS average standard deviation as a percent of the mean value (S1/M1) for both raw data, and data that has been corrected for the effect of density. Properties with the smallest value of this ratio offer the highest confidence that an experimental test average is a valid measure of the true property of the material being tested.

TABLE 8

EFFECT OF DENSITY ON MECHANICAL PROPERTIES OF IMIDITE SA FOAM
IN THE DENSITY RANGE OF 32 to 38 LB/FT³

	Temp	M	B	100 R ²	[100 M/ $\bar{X}$]
Weight Loss after 20 hr at 1150°F, %	--	-0.104	60.89	5.8	0.2
Water Pickup, % (volume)	--	2.16	-31.9	69.	5.1
Heat Distortion Temp (264 psi), °F	--	3.15	660	4.0	0.4
Heat Distortion Temp (66 psi), °F	--	1.74	826	0.2	0.2
Tensile Strength	RT	96.3	-1837	29.	6.6
Tensile Modulus*	RT	6430	84400	58	2.1
Shear Strength	RT	69.8	-811	38.	4.4
Flexure Strength	RT	140	-2131	23.	5.2
Flexure Modulus	RT	-6373	498794	4.8	2.3
Compressive Strength, Vert	RT	147	-2005	43.	4.8
Compressive Strength, Horz	RT	207	-3392	55.	5.4
Compressive Modulus, Vert	RT	4880	126231	14.	1.6
Compressive Modulus, Horz	RT	10113	-3137	26.	2.9
Tensile Strength	500	78.4	-1380	19.	6.0
Shear Strength	500	54.25	-730	28	4.7
Flexure Strength	500	161	-3376	30	7.4
Flexure Modulus	500	-9792	560695	16	4.4
Compressive Strength, Vert	500	79.8	-246	38.	3.2
Compressive Strength, Horz	500	169	-2826	55.	5.5
Compressive Modulus, Vert	500	1848	90980	10.	1.2
Compressive Modulus, Horz	500	3556	55024	21.	2.0

Property = (M) (Density lb/ft³) + B

R = Coefficient of correlation

$\bar{X}$ = Mean property value

* 1 specimen per each of 9 billets

TABLE 9
STANDARD DEVIATION OF RAW DATA RELATIVE TO MEAN (PERCENT)

	TEMP	S1/M1	S2/M2	S3/M3	S4/M4
Tensile Strength	70	13.34	7.68	7.59	15.38
Shear Strength	70	8.58	2.15	3.65	9.74
Flexure Strength	70	13.07	5.52	9.24	14.64
Flexure Modulus $\times 10^5$	70	10.18	2.86	13.53	15.45
Compres Str., Vert	70	8.31	4.93	6.37	9.3
Compres Str., Horz	70	9.06	1.29	4.72	9.4
Compres Mod., Vert $\times 10^5$	70	5.35	4.53	3.82	5.41
Compres Mod., Horz $\times 10^5$	70	6.73	7.98	6.54	7.59
Tensile Strength	500	11.08	5.01	6.08	20.15
Shear Strength	500	13.56	4.67	8.66	10.32
Flexure Strength	500	8.39	4.89	11.99	21.39
Flexure Modulus $\times 10^5$	500	8.18	4.3	15.9	16.79
Compres Str., Vert	500	6.84	3.87	3.28	6.06
Compres Str., Horz	500	10.99	5.22	4.96	9.14
Compres Mod., Vert $\times 10^5$	500	6.15	3.61	3.1	2.94
Compres Mod., Horz $\times 10^5$	500	7	7.96	4.68	4.79

TABLE 10

STANDARD DEVIATION OF CORRECTED DATA RELATIVE TO MEAN (PERCENT)

	TEMP	S1/M1	S2/M2	S3/M3	S4/M4
Tensile Strength	70	13.57	4.25	7.61	14.51
Shear Strength	70	8.67	3.45	5.57	7.98
Flexure Strength	70	13.24	1.92	11.16	13.64
Flexure Modulus $\times 10^5$	70	10.12	4.31	12.65	14.28
Compres Str., Vert	70	8.41	6.6	6.71	6.14
Compres Str., Horz	70	9.18	3.21	4.46	3.73
Compres Mod., Vert $\times 10^5$	70	5.37	3.36	3.95	4.95
Compres Mod., Horz $\times 10^5$	70	6.78	7.34	6.85	6.81
Tensile Strength	500	11.26	1.03	6.99	19.44
Shear Strength	500	13.73	8.07	7.73	7.62
Flexure Strength	500	8.55	1.2	14.19	20.49
Flexure Modulus $\times 10^5$	500	8.09	6.34	14.22	13.49
Compres Str., Vert	500	6.9	3.63	3.5	3.92
Compres Str., Horz	500	11.15	3.98	4.29	3.99
Compres Mod., Vert $\times 10^5$	500	6.17	2.86	2.64	2.33
Compres Mod., Horz $\times 10^5$	500	7.04	6.42	4.04	3.93

Similarly, it is important that the standard deviation of repeat trials of the same variable be small. A measure of this property is presented in the tables as $S2/M2$, where $S2$ is the standard deviation of the averages of three lots of foam made from IMIDITE SA powder Batch 91-1 (Billets 1, 7, and 8).

The standard deviation between different batches of IMIDITE SA powder or different batches of IMIDITE 2801 prepolymer should be small. A large variation here would mean that an unnecessarily large decrease in the sample average must be observed before the decrease could be considered as significant. These properties are measured in the tables as $S3/M3$ and $S4/M4$. $S3$ is the standard deviation of the four averages of billets made from IMIDITE powder Batches 91-1, 91-2, 91-3, and 91-4, and $S4$ is the standard deviation of the four averages of billets made with IMIDITE 2801 prepolymer, Batches 89, 90, 91, and 92.

All of these standard deviations should be small, however, certain ratios of the standard deviation (variance) can be either large or small*. These ratios are presented in Tables 11 and 12. The ratio $S2/S1$ is a comparison of the deviations between billets made from the same batch of IMIDITE SA powder and those deviations which are inherent in testing specimens from a billet. A value of 0.5 for this ratio is an expected value for the case that each of the billets tested had the same average. As this ratio increases, it becomes more probable that these averages are actually different values. Since these billets were made from the same batch of IMIDITE SA powder, variations in the ratio of $S2/S1$ must be caused by something other than the quality of the IMIDITE powder batch. The densities of the three billets in question is relatively constant, and it can be assumed that a large variation in the ratio is caused by differences in the molding procedure or cure cycle.

While a small value for the ratio of $S2/S1$ is desired, large values are preferred for the ratios of $S3/S2$ and $S4/S3$. These ratios represent the sensitivity of the test to detect differences between batches of IMIDITE SA powder and batches of IMIDITE 2801 prepolymer respectively. A value of 1.0 or less indicates that the test does not differentiate between these batches. As values increase over 1.0 there is resulting ease in variation detection.

Non-statistical factors which must also be evaluated are the relative sizes of variations caused by changes in density and cure cycle. The only available data on the effect of densities was presented previously in Table 8. In this table the ratio of the slope of the least squares line to the mean value is the best measure of the relative effect of densities, however, it is also important to consider the goodness of fit of the data.

* This is more properly treated by an "analysis of variance". However, the treatment presented is valid as all of the mean values are averages of the same number of specimens (5).

TABLE 11

RATIO OF STANDARD DEVIATIONS OF RAW DATA

	TEMP	S2/S1	S3/S2	S4/S3
Tensile Strength	70	0.643	0.946	1.91
Shear Strength	70	0.253	1.716	2.62
Flexure Strength	70	0.454	1.637	1.516
Flexure Modulus $\times 10^5$	70	0.307	4.543	1.095
Compres Str., Vert	70	0.563	1.352	1.469
Compres Str., Horz	70	0.135	3.774	2.028
Compres Mod., Vert $\times 10^5$	70	0.87	0.833	1.398
Compres Mod., Horz $\times 10^5$	70	1.241	0.793	1.147
Tensile Strength	500	0.518	1.176	3.017
Shear Strength	500	0.357	1.813	1.176
Flexure Strength	500	0.679	2.297	1.649
Flexure Modulus $\times 10^5$	500	0.58	3.53	1.008
Compres Str., Vert	500	0.555	0.865	1.845
Compres Str., Horz	500	0.452	0.97	1.891
Compres Mod., Vert $\times 10^5$	500	0.577	0.874	0.948
Compres Mod., Horz $\times 10^5$	500	1.107	0.592	1.041

TABLE 12

RATIO OF STANDARD DEVIATIONS OF CORRECTED DATA

	TEMP	S2/S1	S3/S2	S4/S3
Tensile Strength	70	0.358	1.713	1.762
Shear Strength	70	0.409	1.626	1.388
Flexure Strength	70	0.158	5.684	1.151
Flexure Modulus $\times 10^5$	70	0.461	2.822	1.09
Compres Str., Vert	70	0.758	1.061	0.908
Compres Str., Horz	70	0.339	1.429	0.839
Compres Mod., Vert $\times 10^5$	70	0.646	1.163	1.229
Compres Mod., Horz $\times 10^5$	70	1.145	0.903	0.974
Tensile Strength	500	0.107	6.551	2.489
Shear Strength	500	0.62	0.935	0.96
Flexure Strength	500	0.168	11.011	1.307
Flexure Modulus $\times 10^5$	500	0.852	2.142	0.917
Compres Str., Vert	500	0.523	0.98	1.11
Compres Str., Horz	500	0.347	1.096	0.939
Compres Mod., Vert $\times 10^5$	500	0.459	0.936	0.88
Compres Mod., Horz $\times 10^5$	500	0.894	0.633	0.983

to the line. This value is represented by R^2 which is the percent of the variance which can be attributed to density. The ideal situation for these parameters is a minimum slope with an R^2 value at 100%, conversely a high relative slope and low correlation factor will produce misleading results.

One measure of the effect of the cure cycle on the properties has been discussed above; this was the ratio of S_2/S_1 . However, another measure of this property is the relative difference between data obtained from Billet 11 and the average of the other nine billets. This data is contained in Table 7.

Arbitrary weighted values were assigned to each of the variables mentioned above. These values were summed up for each of the 16 properties in question and the arbitrary analysis scores are shown in Table 13. The lowest score represents tests which best determine the quality of the IMIDITE SA powder, while higher score values are the measure of other variables.

However, a final discussion on which properties of IMIDITE SA foam should be measured to ensure its quality must be based not only on the above estimation but also on how critically each of these properties affects the desired end use of the material.

To aid in the selection of critical properties, the table also includes minimum values for which Whittaker can certify these properties at 1, 5, and 10% rejection levels.

COMPRESSIVE STRENGTH AND MODULUS

An examination of compressive strength and modulus data at room temperature and 500°F show an appreciable difference when the foam is tested in different directions. For the sake of clarification, the vertical direction is tested in an axis parallel to the travel of the mold plunger, while the horizontal direction is at right angles to this travel.

Using an analysis of variance technique, there is 99.9% confidence that in each of these 4 cases the horizontal value is better than the vertical value.

Because of the large difference of compressive values in the two directions, it can be assumed that there are corresponding differences in the other mechanical properties in the two directions. Unfortunately, there is no data available from which an analysis can be made. The orientation of specimens other than compressive was not recorded on Billets 1 through 8 and 11. While the orientation in Billet 9 was controlled, no conclusion can be reached from the data.

TABLE 13

SCORE OF STATISTICAL ANALYSIS AND MINIMUM VALUES
AT THREE CONFIDENCE LEVELS

Property	Test Temp.	Analysis Score	$\bar{X}$	$\sigma_{\bar{X}}$	A Value 10%	A Value 5%	A Value 1%
Flexure Modulus	RT	51	2.81	0.403	2.19	1.95	1.30
Comp Str, Horz	RT	51	3760	167	3504	3404	3134
Shear Strength	RT	53	1570	126	1377	1301	1098
Tensile Strength	500	57	1275	251	890	740	335
Comp Mod, Vert	RT	58	2.95	0.146	2.73	2.64	2.40
Flexure Strength	RT	65	2659	365	2099	1880	1291
Flexure Strength	500	65	2129	441	1453	1189	477
Comp Mod, Vert	500	68	1.55	0.041	1.49	1.46	1.40
Comp Str, Vert	500	77	2506	98	2356	2297	2139
Flexure Modulus	500	85	2.26	0.334	1.75	1.55	1.01
Comp Str, Horz	500	89	3008	128	2812	2735	2528
Comp Mod, Horz	500	91	1.78	0.071	1.67	1.63	1.51
Comp Str, Vert	RT	92	3068	207	2751	2627	2292
Tensile Strength	RT	99	1438	211	1115	988	647
Comp Mod, Horz	RT	105	3.46	0.243	3.09	2.94	2.55
Shear Strength	500	115	1131	90	993	939	794

Note: (1) All values corrected to 34 lb/ft³ density using least squares line equations

(2) A values are based on the average of 5 specimens.

(3) $A = \bar{X} - (\sigma_{\bar{X}})(T)$

$T_{.10} = 1.53$

$T_{.05} = 2.13$

$T_{.01} = 3.75$

If it is assumed that there is a difference of mechanical properties in these two directions for all of these tests, then some of the variation of the flexure and heat distortion test can be attributed to this area. However, because of the way the specimens were cut from the billets, this problem will not effect the tensile or shear data.

HEAT-DISTORTION TEMPERATURE

Heat-distortion temperatures were determined by a procedure modified from the original ASTM method as described under the Experimental Section. It was necessary to relieve stresses in the specimen by annealing them at 700°F for 16 hours. Presumably, these stresses were developed when the billets cooled and/or during machining. An example of a heat-distortion cure for an unrelieved specimen is shown in Figure 2, and a relieved specimen in Figure 3.

WATER ADSORPTION

Presumably, a study of the amount of water adsorbed by IMIDITE SA foam was conducted to measure the open-cell, void content of the foam. However, as mentioned previously, a moderately high degree of negative correlation was observed between these two properties.

A comparison of water adsorption of a high-and-low density sample is shown in Table 14. The original analysis, referred to above, did not include measurement of volume swelling, and, as a result the analysis was repeated to determine this variable. As can be seen from the data, the two analyses are in good general agreement, and the calculated void content is in moderately good agreement with the theoretical value for the specimens from Billet 9. The large variation between the observed and expected values for Billet Number 6 has not been satisfactorily explained.

It is known that polybenzimidazole prepolymers and polymers are hygroscopic and samples of IMIDITE SA foam exhibits a reversible and rapid weight and dimensional change with changes in humidity. However, it is unlikely that specimens from Billet 6 have picked up chemically bound water, because the samples return to their original weight after drying overnight at 120°C under full vacuum.

It should be noted that water adsorbed by the polybenzimidazole polymer will presumably effect its mechanical properties. It is, therefore, important to realize that the mechanical test specimens reported herein were stored in ambient air prior to testing, and therefore are not of artificially high values which could be obtained by dry storage.

Figure 2. Deflection vs. Temperature Curve (Specimen not stress relieved)

Figure 3. Deflection vs. Temperature Curve
(Specimen stress relieved at 700°F for 6 hours)

TABLE 14

WATER ADSORPTION OF IMIDITE SA FOAM

Billet Number	Billet Density	Theoretical Void Content % by Volume*	Initial Analysis	Repeat Analysis		Calculated Void Content % by Volume
			Water Pickup % by Volume Avg of 3	Water Pickup % by Volume Avg of 2	% Swelling by Volume	
6	38.3	13	49.5	54.5	8.0	46.5
9	31.7	28	35.8	39.5	7.2	32.3

$$* \text{Theoretical Void Content} = \left(\frac{44 - \text{Density (lb/ft}^3\text{)}}{44} \right) \times 100$$

where 44 is the theoretical density based on a composite deviation of the raw materials.

ISOTHERMAL WEIGHT LOSS

Isothermal weight loss at 650°F does not appear to be a satisfactory test for quality control purposes because the material continues to lose weight with time until all of the organic material is gone (see Figure 4). Studies also showed that the test was not reproducible from one oven to another, or even in the same oven when the tests were run at different times. However, data run at the same time does show statistically significant differences between billets.

In contrast to isothermal weight loss at 650°F, burnout at 1150°F is an excellent test of the resin content of the foam. Based on the data obtained ($\bar{X} = 57.3$; $S_{\bar{X}} = 0.85$; $N = 9 \times 3$), weight loss requirement (average of 3) should be set at 55 to 60% for 2% rejection to 56 to 59% for 10% rejection level.

HARDNESS

A limited study of Shore D hardness indicated that this test may be a satisfactory quality control test for production parts, however, sufficient data was not obtained to set limits for such a test procedure.

A minimum amount of data indicates that the hardness is related to cure as one billet tested 54 prior to postcure and 63 after postcure. Also Billet 11, with the extended postcure, tested 66.

The hardness is also probably related to density as Billet 6 (density = 38.3) tested 64 while Billet 9 (density = 31.7) tested 58.

It is also interesting to note that Billet 9 showed a statistically significant difference between the bottom and top (next to plunger) surface. Tensile specimen taken from near the bottom showed a hardness of 58; in the middle, 61; and at the top 63. While the difference was real for this billet, a general conclusion cannot be reached because this effect was not checked on other billets.

THERMAL CONDUCTIVITY

Thermal conductivity test specimens representing Billets 1 through 9 have been prepared and forwarded to Bendix-K.C. for testing, however, no data has been made available at this date.

Thermal conductivity data obtained previously at WRD indicates a value of about 0.035 to 0.065 BUT ft/°F hr ft² in the 250° to 500°F range.

Figure 4. Isothermal Weight Loss at 650°F of IMIDITE SA Foam

RAW MATERIAL STUDIES

IMIDITE 2801 Prepolymer

IMIDITE 2801 is a condensation prepolymer of an aromatic amine and phenyl ester, resulting in a low molecular weight polybenzimidazole prepolymer with phenol and water byproducts.

With additional heating, this prepolymer liberates additional phenol and water, and advances to a high molecular weight, thermally stable polymer.

Because the manufacturing procedure requires that the condensation reaction be stopped at partial completion, the variation of properties attained from the prepolymer are much greater than is observed for most commercial materials. These variations are evidenced by variations in such properties as melting point, volatile content, and flow characteristics. Although the material has these noticeable variation in handling characteristics, the properties of the cured polymer are relatively uniform.

Another problem area with the prepolymer is that it darkens on exposure to light or air. It is believed that this darkening of color results from highly colored oxidation products of the aromatic amine that are present in the material. While there is no evidence to indicate that this darkening is detrimental to mechanical properties of IMIDITE SA foam, foam made from IMIDITE 2801 Batch 89 (which had darkened on standing) was more dense and had greater flow during cure than billets made with lighter colored material.

A test has been developed to measure the color of either IMIDITE 2801 prepolymer or the IMIDITE SA powder (see Experimental Section). The procedure compares the adsorbance of an acetone extract of the material at 435 m μ to the adsorbance at 343 m μ . The adsorbance at 435 m μ is dependent upon the amount of colored material present, while the adsorbance at 343 m μ is related to the amount of prepolymer in solution. Typical adsorbance curves for dark and light material are shown in Figure 5. A differential adsorbance curve, showing the adsorbance of the dark material over the light materials, is shown in Figure 6.

The results of determining the color index of six batches of IMIDITE 2801 prepolymer is shown in Table 15. The color of Batches 92, 91, and 90 (index 0.247, 0.289, and 0.335) are considered to be characteristic of fresh material. Batch 89 material is considered to be borderline (index 0.752). It is interesting to note that this material was more soluble in

Figure 5. Adsorption Curve for IMIDITE 2801 Prepolymer

Figure 6. Differential Adsorption Curve for IMIDITE 2801 Prepolymer

acetone (adsorbance 1.25 at 343 m μ) than the other batches, indicating that the material may be of lower molecular weight, which, in turn, may explain the greater flow in the billet made from this batch. IMIDITE 2801 prepolymer Batches 69 and 83 were very dark in color, and are assumed to be unacceptable, however, no IMIDITE SA foam data is available to support this conclusion.

TABLE 15

COLOR INDEX OF BATCHES OF IMIDITE 2801 PREPOLYMER

Batch No.	Adsorbance at 435 m μ	Adsorbance at 343 m μ	Index	Notes
92	0.240	0.97	0.247	
91	0.263	0.91	0.289	
90	0.345	1.03	0.335	
89	0.940	1.25	0.752	Slight darkening
83	0.915	1.02	0.897	Dark
69	1.42	1.01	1.406	Three years old; very dark red-brown

Other tests, including melting point, TGA weight loss and sieve analysis, were studied. Acceptance values and procedures for all of the tests were established and included in a material specification (Appendix C). Melting point and TGA data are shown in Table 16. It is interesting to observe the variation in melting points observed at NMD and WRD. This variation is due to the wide melting point range of the IMIDITE 2801 prepolymer, which in reality is a gradual softening and melting over the range. Typical TGA curves under air and nitrogen are shown in Figures 7 and 8.

Silica Microballoons

A test method to determine the bulk density of silica microballoons has been established (see Experimental Section). Because the density is believed to be the only property of this material that is important to the IMIDITE SA foam, no other studies of this material were conducted.

A material specification was prepared, based primarily on data supplied by the vendor. This specification is included as Appendix D.

TABLE 16

QUALITY CONTROL DATA FOR-IMIDITE 2801 PREPOLYMER

Batch No.	Mfg Date	NMD m.p., °C	WRD m.p., °C	TGA Analysis			
				Volatile Content, Air % at 375°C	Volatile Content, N ₂ % at 375°C	Decomposition Temp, °C	Wt. Loss at 500°C, N ₂ %
69	5/66	94-122 (5/66)	112-128 (5/69)	(NMD 25%)		--	--
83	8/67	99-129	111-123	--	--	--	--
89	--	105-122	111-130	26	24	550	36
90	12/68	106-132	114-133	26	27	556	41
91	2/69	--	118-133	27	28	557	42
92	6/69	--	99-127	24	--	543	--

Figure 7. Thermal Gravimetric Analysis of IMIDITE 2801 in Air

Figure 8. Thermal Gravimetric Analysis of IMIDITE 2801 in Nitrogen

Alumina-Silica Fibers

A ceramic fiber (Kaowool Bulk A) is used in IMIDITE SA powder as a reinforcement and an aid to the removal of volatiles.

Upon contacting the vendor of this material, it was revealed that the Bulk-A form of the material contains a lubricant. Because the lubricant is normally removed by heating at 1000°F, it is apparent that our process of drying the material for 1 hour at 600°F does not remove all of the lubricant. And because the lubricant will presumably decrease the bonding of the fiber to the matrix, a stronger mechanical property could be obtained with a lubricant-free material. However, a study of this problem was not conducted as it is not within the scope of the present program.

It is believed that the most important property of ground material, as it is used in the IMIDITE SA powder, is the fiber length, however, attempts to measure this property have not been rewarding. The material, being fibrous, tends to ball up; separation of these balls results in additional fiber breakage. In addition, when these fibers are spread out for viewing under a microscope, the short fibers are lost from the balls first, and the longer fibers tend to remain together or to come apart in local areas. As a result, measurements of this property result in no statistical confidence of the mean.

Attempts to relate this property to sieve analysis were also unrewarding because the fibrous material does not go through a fine mesh sieve without mechanical assistance.

As a result of these problems, a satisfactory test for fiber length was not obtained, and this property currently remains an uncontrolled variable.

A study of other variables of Kaowool Bulk A was limited to obtaining test methods to measure fiber diameter and silica content. These are to be used as acceptance tests of the raw material, and are included in a material specification (Appendix E).

IMIDITE SA POWDER MATERIAL STUDIES

Color Test

The color test used to determine the degree of oxidation of IMIDITE 2801 prepolymer, which has been discussed previously, is also applicable to IMIDITE SA powder. It is recommended that this test (see Experimental Section) be included in the material specification for IMIDITE SA powder, and that an acceptance value for the index be set between 0.5 and 0.8, depending upon the acceptability of data from Billet 6. This test would also be convenient for re-qualification of IMIDITE SA powder that has exceeded its shelf life.

Resin Content of IMIDITE SA Powder

A new procedure has been developed for determining the resin content of IMIDITE SA powder by solvent extraction with pyridine. This procedure was selected over the more simple procedure of resin-burn in a crucible due to the potential of splattering and foaming of the resin at elevated temperatures. This procedure also has the advantage that it will not extract high molecular weight resin which has been advanced too far. If there is an appreciable amount of this advanced resin present, the test result by solvent extraction will be unacceptable, while it would go unnoticed in the burn off procedure.

It is recommended that this procedure (see Experimental Section) be included in a material specification as a control of formulation variables for IMIDITE SA powder.

Volatile Content

A method to determine volatile contents of IMIDITE SA powder was developed, however, the volatile contents of the various batches of IMIDITE SA powder used on the program were not determined. The method is described in the Experimental Section and is briefly a weight loss determination on heating a sample to 800°F under nitrogen. Acceptance limits for the procedure described should be set at 14 to 20 percent.

This test has limited value in a materials specification for IMIDITE SA foam as the test results are generally not reproducible, particularly when different ovens (heat up rates) are used.

This method can also be used to determine resin content, however, the solvent extraction technique is the preferred method.

Lap Shear Strength

A procedure was investigated in which lap shear bonds can be made from the resin portion of the IMIDITE SA powder. The basic procedure for this test, originally developed at WRD, is used by the resin manufacturer

as a quality control test for IMIDITE 2801 prepolymer. While this procedure is a good test to measure the quality of the resin portion of the IMIDITE SA powder, it is also time consuming and requires considerable technician training, making it not recommendable as a satisfactory quality control method for IMIDITE SA powder.

The test procedure involves dissolving the resin portion of the IMIDITE SA powder in pyridine, filtering out the Kaowool and Eccospheres, concentrating the solution, adding aluminum powder, and making bonds on stainless steel adherend by a slow resin-buildup solvent evaporation technique. The cured bonds are then tested at room temperature and at 700°F.

Test results obtained on a single set of bonds made from Batch 91-1 IMIDITE SA powder are:

	<u>Avg</u>	<u>Std. Dev.</u>	<u>No. of Spec.</u>
Room Temperature	2940 psi	235	4
700°F	2282 psi	421	4

These numbers are slightly lower than the normal rejection levels of 3000 and 2300 psi for IMIDITE 2801 prepolymer; however, it is felt that this is due to the additional handling required.

Shelf Life of IMIDITE SA Powder

There are two apparent factors that affect the shelf life of the IMIDITE SA powder: The color change of the IMIDITE 2801 prepolymer which has already been discussed, and the separation of the IMIDITE SA powder ingredients due to handling and vibration. This separation is the result of greatly different densities of the component raw materials, and the tendency of the ceramic fibers to "ball-up".

Both of these factors, which effect storage life, could be overcome to some degree by supplying the IMIDITE SA powder in the form of compressed pellets, or granulated preformed material. However, a study of this problem is not within the scope of the present program.

Data on the effect of storage life of the IMIDITE SA powder is limited, however, of the seven batches studied on this program, Batch 89-1 had the longest shelf life of four months prior to use. The billets (No. 6) made from this material were more dense, exhibited more flow during cure and were darker than the others. The mechanical properties of the foam were as good or better than the other foam; this is due primarily to the higher density of the foam. Because of these variations in properties, this batch of foam is considered to be of borderline quality.

On the basis of the above information, and the 90-day warranty period on the IMIDITE 2801 prepolymer, Whittaker R&D feels that an equal 90-day warranty period from the date of manufacture of IMIDITE SA powder is all that is indicated at this time.

RECOMMENDED FUTURE WORK

1. A study should be conducted to optimize the foam postcure cycle.
2. A material specification should be prepared for IMIDITE SA powder, to call out minimum values for specified mechanical tests.
3. Additional data should be collected as new batches of IMIDITE 2801 prepolymer and IMIDITE SA powder become available.

EXPERIMENTAL SECTION

Color Test Procedure

Weigh a 100-150 mg sample of IMIDITE SA powder into a 50-ml stoppered flask. Add $[0.325 \times \text{sample weight (mg)}]$ ml ± 1 ml of spectrograde acetone. Shake vigorously for exactly two minutes. Immediately filter the solution through a coarse filter paper, collecting about 10 ml of filtrate.

Dilute 1.00 ml of this solution to 100 ml with additional acetone.

Determine the adsorbance of the dilute solution at 343 m μ and the adsorbance of the undiluted solution at 435 m μ , using acetone as a reference in each case.

$$\text{Color index} = \frac{\text{Adsorbance of concentrated solution at 435 m}\mu}{\text{Adsorbance of dilute solution at 343 m}\mu}$$

Note: The entire procedure should be completed in minimum time because the color is time dependent.

Resin Content Procedure

Wash three 33 x 94 mm soxhlet thimbles with pyridine, followed by acetone; dry for 2 hours at 150°C. Weigh 5 to 7 grams of IMIDITE SA powder into each thimble; extract with pyridine for 2 hours, allowing a minimum of 20 cycles.

Wash the thimbles with acetone; dry for 2 hours at 150°C, and reweigh.

$$\text{Resin content (\%)} = \frac{(\text{weight of sample} - \text{weight of residue})}{\text{Weight of sample}} \times 100$$

The average of three determinations shall be 63 to 67%, having a standard deviation of less than 0.9.

Volatile Content Procedure

Weigh 1 gram of IMIDITE SA powder into an ignited size 1 porcelain crucible. Heat the uncovered crucible for 1 hour at 800°F, under nitrogen. Cool to room temperature and reweigh.

$$\text{Volatile content} = \frac{(\text{initial weight} - \text{final weight})}{\text{initial weight}} \times 100$$

The average of three weight loss determinations shall be reported as the volatile content.

Note: The resin content can be determined by heating the crucibles for an additional 20±4 hours at 1150°F in air.

$$\text{Resin Content} = \frac{(\text{initial sample weight} - \text{final weight})}{\text{Initial sample weight}} \times 100$$

Lap Shear Bond Strength

IMIDITE SA powder (15 g) is boiled in 20 ml of reagent grade pyridine and filtered; the residue is again boiled in 20 ml of reagent grade pyridine and filtered. The residue is washed twice with 10 ml portions of reagent grade pyridine. The combined filtrates are concentrated to a concentration of approximately 10 g solids/20 ml pyridine.

This solution is used to prepare bonds per Narmco Materials Division (NMD) specifications SOP-QC-PT-6 and SOP-QC-SP-12.

Bonds are tested at room temperature and at 700°F in accordance with NMD-SOP-QC-MT-8.

Note: These specifications are available on request. However, they are not included herein to protect the proprietary position of NMD.

Billet Manufacturing Procedure

Molds

Two molds are used: a large mold 10-1/2 in. x 10 in. x 3-1/2 in. inside dimension and a smaller mold 8-1/4 in. x 8-1/4 in. x 4 in. inside dimension. Both molds having 3/8-in. steel construction and a break-away design with bolted sides and free moving base plate and plunger. A thin perforated metal plate is also incorporated immediately below the plunger to assist in removal of volatiles.

Mold surfaces are prepared with an initial baked-on coating of DC20 release agent, in addition to a coat of Mold Wiz release agent prior to making each billet.

Molding Procedure

IMIDITE SA powder is packed into the mold cavities by moderate tamping. 1400 g is placed in the larger mold while 1000 g is placed in the smaller mold.

The molds are closed and both are placed on a single steel plate. The molds are covered with several layers of glass cloth to act as bleeder and to protect the vacuum bag from the sharp corners of the mold. The assembly is vacuum-bagged, using 3 mil Kapton polyimide film and Universal

Sealant UHT (Grey) vacuum bag sealant compound. The bag is then clamped in place, using a steel frame.

A 30-in. Hg vacuum is applied through a vacuum port in the Kapton film, and the assembly is cured in a cam-controlled oven as follows:

30 minutes $\pm$ 10 minutes @ 250 $\pm$ 10°F
40 minutes $\pm$ 10 minutes @ 300 $\pm$ 10°F
60 minutes $\pm$ 15 minutes @ 350 $\pm$ 15°F
60 minutes $\pm$ 15 minutes @ 400 $\pm$ 15°F
60 minutes $\pm$ 15 minutes @ 450 $\pm$ 20°F
60 minutes $\pm$ 15 minutes @ 500 $\pm$ 20°F
60 minutes $\pm$ 15 minutes @ 550 $\pm$ 20°F
30 minutes $\pm$ 10 minutes @ 600 $\pm$ 20°F

The two billets are cooled in the molds under vacuum, placed in a steel retort and postcured in a cam-controlled oven, using a preheated argon gas purge (flow rate equivalent to 3-l/min of air). The postcure cycle is:

120 minutes $\pm$ 15-minute rise time from room temperature to 600°F $\pm$ 20°F
60 minutes $\pm$ 10-minute rise time from 600°F $\pm$ 20°F to 700 $\pm$ 20°F
20 minutes $\pm$ 5 minutes @ 700 $\pm$ 20°F
60 minutes $\pm$ 10-minute rise time from 700°F $\pm$ 20°F to 800 $\pm$ 20°F
20 minutes $\pm$ 5 minutes @ 800 $\pm$ 20°F
30 minutes $\pm$ 10-minute rise time from 800 $\pm$ 20°F to 850 $\pm$ 20°F

The postcured billets are removed from the retort after cooling to room temperature under constant argon flow.

Specimen Preparation

All test specimens, except the thermal-conductivity specimens, are machined from the larger billet, using the pattern shown in Figure 9. A pair of 8-inch diameter thermal conductivity specimens is machined from the other billet.

A minimum of 1/16-inch is machined from each molded surface to eliminated edge effects.

Specimens are cut and machined, using water or a coolant; final specimen surfaces are as obtained from diamond cut-off wheels or surface grinders.

Samples are dried at 120 $\pm$ 10°C for 2 hours under 30 in. Hg vacuum, and stored in an air-conditioned building prior to testing.

Figure 9. Layout of 54 Test Specimens in
Large Molding Size: 10 x 10.5 x 1.25.

Mechanical Tests

Mechanical testing was accomplished in accordance with ASTM test methods contained in Table 17.

TABLE 17
MECHANICAL TEST PROCEDURES

Test	ASTM Method	Specimen Size, in.	Test Temp	Number of Tests
Tensile Strength	D638	1/4 x (1/2 & 3/4) x 8.5	RT	5
			500°F	5
Shear Strength	D732	2 x 2 x 1/2	RT	5
			500°F	5
Compression (2 directions)	D1621	1/2 x 1/2 x 1	RT	5 x 2
			500°F	5 x 2
Flexure Strength	D790	1/2 x 1/2 x 10	RT	5
			500°F	5

Heat-Distortion Temperature

Heat-distortion temperatures were determined by using 5.0 x 0.5 x 0.5-inch specimens and a procedure modified from ASTM-D648-56. The method followed the ASTM method, with the following exceptions.

1. The specimens were annealed at 700°F for 16 hours under argon to relieve stresses.
2. Temperatures were taken from a thermocouple placed in a hole drilled in the specimen.
3. The specimens were placed in an oven at 500°F for 264 psi loading and 650°F for 66 psi loading; the load, calculated by the method described in the ASTM procedure, was applied 2 minutes after the specimen reach temperature.

4. The specimens were heated in an air oven at 5 degrees per minute.
5. The heat-distortion temperature is the temperature that the specimen deflects 0.010 inch, assuming zero deflection at the starting temperature.

Isothermal Weight Loss

Three specimens (0.20 x 0.50 x 1.00-inch) are dried for 2 hours at 120°C under full vacuum. The specimens are placed in separate, weighed, ignited crucibles, and the specimen weight determined. The crucible and sample are then placed in a 650⁺¹⁰₋₀°F air circulating oven for 60 hours, cooled, and reweighed. The percent weight loss calculated, and the average of three determinations, is reported as the weight loss (650°F).

The specimens are then placed in an 1150 ±50°F furnace (static air) for 20 ±4 hours, and the weight loss at 1150°F is calculated as follows:

$$\text{Weight loss at 1150°F} = \frac{(\text{Initial sample wt} - \text{wt after 1150°F burnout})}{\text{Initial Sample Weight}} \times 100$$

The average of three specimens is reported.

Note: If 650°F weight loss is not required, specimen can be placed directly into 1150°F furnace.

Water Adsorption

Three 0.20 x 0.50 x 1.00-inch specimens are dried 2 hours at 120°C under full vacuum, cooled and weighed. The specimens are placed in a beaker of distilled water and held at least 1 inch below the surface with a restrainer. The water is brought to a boil and held at a full boil for 1 hour. The water is then cooled to ambient temperature, using ice; contact of the specimen with the atmosphere is avoided. The specimens are then removed from the water, towel-dried to remove excess water, and weighed.

The water adsorption is calculated as follows:

$$\text{Water Adsorption} = \left(\frac{\text{Weight wet} - \text{Weight dry}}{\text{Weight dry}} \right) \left(\frac{\text{Specimen Density, lb/ft}^3}{62.4} \right) (100)$$

(% by volume)

The average of three specimens is reported.

Weight Loss During Water Boil.

Specimens from the above procedure are dried for 16 hours at 120°C under full vacuum. The weight loss is determined as follows:

$$\text{Wt Loss} = \left(\frac{\text{Initial Dry weight} - \text{Final dried weight}}{\text{Initial Dry weight}} \right) (100)$$

APPENDIX A

COMPUTER PRINT OUTS OF RAW MECHANICAL TEST DATA

TENSILE STRENGTH

ROOM TEMPERATURE TEST

ASSUME THE DENSITY IS EQUAL TO $(-T/L/W/T) \times 2.90561$

LENGTH	WIDTH	THICK.	WEIGHT	DENSITY	LOAD	STRENGTH
BILLET NUMBER 1						
8.5	.503	.251	12.25	33.2	178	1410
8.51	.508	.25	12.24	33.3	184	1466
8.5	.502	.25	12.46	33.9	200	1594
8.51	.503	.248	12.49	34.2	192	1539
8.52	.501	.251	12.86	33.2	180	1431
AVERAGE				33.6		1488
STD DEV				.46		76.7
BILLET NUMBER 2						
8.55	.498	.25	12.42	33.9	205	1647
8.56	.496	.25	12.81	35.1	255	2056
8.55	.501	.25	12.6	34.2	180	1437
8.56	.503	.249	12.54	34	144	1150
8.57	.499	.251	12.57	34	178	1421
AVERAGE				34.2		1542
STD DEV				.48		337.3
BILLET NUMBER 3						
8.54	.501	.25	12.27	33.3	183	1461
8.55	.501	.25	12.1	32.8	192	1533
8.55	.5	.25	12.29	33.4	176	1408
8.55	.501	.25	12.36	33.5	185	1477
X.56	.502	.25	11.99	32.4	156	1243
AVERAGE				33.1		1424
STD DEV				.46		110.7
BILLET NUMBER 4						
8.51	.5	.25	12.58	34.4	174	1392
8.51	.503	.25	12.77	34.7	204	1622
8.52	.498	.25	12.64	34.6	165	1325
8.52	.505	.25	12.63	34.1	176	1394
8.51	.501	.251	12.7	34.5	188	1495
AVERAGE				34.5		1445
STD DEV				.22		115.8
BILLET NUMBER 5						
8.53	.5	.249	12.54	34.3	125	1004
8.52	.492	.252	12.72	35	222	1791
8.52	.498	.248	12.61	34.8	198	1603
8.51	.501	.25	12.99	35.4	200	1597
8.51	.5	.245	12.37	34.5	146	1192
AVERAGE				34.8		1437
STD DEV				.43		326.2
BILLET NUMBER 6						
8.53	.502	.251	13.86	37.5	190	1508
8.53	.503	.249	13.66	37.2	170	1357
8.53	.504	.25	14.13	38.2	214	1698
8.52	.500	.251	13.89	37.6	187	1484
8.51	.498	.251	13.88	37.9	195	1560
AVERAGE				37.7		1521
STD DEV				.4		123.8
BILLET NUMBER 7						
8.51	.501	.251	12.6	34.2	201	1598
8.5	.498	.252	12.45	33.9	226	1801
X.5	.507	.251	12.41	33.3	210	1650
8.5	.504	.251	12.65	34.2	223	1763
8.5	.5	.251	12.53	34.1	221	1761
AVERAGE				34		1714
STD DEV				.37		86
BILLET NUMBER 8						
8.51	.498	.25	12.88	35.3	205	1647
8.5	.503	.25	12.97	35.3	215	1710
8.5	.503	.251	12.74	34.5	207	1640
8.48	.504	.25	12.68	34.5	240	1905
8.5	.507	.25	12.84	34.6	200	1578
AVERAGE				34.6		1695
STD DEV				.42		125.8
BILLET NUMBER 9						
8.52	.498	.242	10.866	30.7	80	664
8.52	.495	.247	11.733	32.7	145	1186
8.52	.496	.246	11.869	32.1	130	1057
8.52	.5	.248	11.32	31.1	85	685
8.52	.5	.249	11.566	31.7	110	884
AVERAGE				31.7		895
STD DEV				.78		228.2

GRAND AVERAGE STRENGTH 1462.7
STANDARD DEVIATION 227.36

GRAND AVERAGE DENSITY 34.85
STANDARD DEVIATION 1.59653
RELATION BETWEEN STRENGTH AND DENSITY

STRENGTH = 96.3303 TIMES DENSITY (LBS/FT³) PLUS -1837.02
COFF. OF CORRELATION .535198

SHEAR STRENGTH
ROOM TEMPERATURE DATA

LENGTH	WIDTH	THICK.	WEIGHT	DENSITY	LOAD	STRENGTH
BILLET NUMBER 1						
2.01	2.012	.502	17.73	33.3	3235	1601
2.011	2.012	.502	17.82	33.4	3285	1686
2.011	2.01	.502	17.84	33.5	3290	1630
2.011	2.012	.502	17.76	33.3	3230	1599
AVERAGE				33.4		1614
STD DEV				.1		16.3
BILLET NUMBER 2						
2.011	2.011	.502	18.21	34.2	3575	1771
2.01	2.012	.502	18.23	34.2	3375	1671
2.011	2.011	.502	18.5	34.7	3580	1773
2.011	2.011	.502	18.29	34.3	3490	1729
AVERAGE				34.4		1735
STD DEV				.25		47.9
BILLET NUMBER 3						
2.016	2.008	.502	17.99	33.7	3360	1667
2.011	2.008	.502	17.87	33.6	3365	1669
2.011	2.008	.502	17.58	33	3235	1605
2.004	2.016	.502	17.39	32.6	3125	1544
2.011	2.007	.502	17.73	33.3	3385	1680
AVERAGE				33.3		1632
STD DEV				.45		57.8
BILLET NUMBER 4						
2.016	2.008	.503	18.696	35	3300	1634
2.013	2.012	.502	18.539	34.7	3110	1540
2.008	2.012	.501	18.611	35	3105	1540
2.016	2.012	.502	18.613	34.8	3340	1653
2.012	2.017	.502	18.529	34.7	2830	1397
AVERAGE				34.8		1552
STD DEV				.16		101.4
BILLET NUMBER 5						
2.019	2.015	.496	18.032	34	2320	1161
2.015	2.011	.499	18.006	33.9	2615	1303
2.015	2.015	.496	18.783	35.5	2730	1366
2.016	2.009	.502	18.957	35.5	3400	1686
2.018	2.017	.494	18.639	35.3	2660	1335
AVERAGE				34.9		1369
STD DEV				.81		193.1
BILLET NUMBER 6						
2.005	2.011	.452	18.621	38.9	3720	2046
2.018	2.011	.449	18.152	38	3160	1750
2.015	2.011	.448	18.283	38.4	3210	1781
2.014	2.006	.452	18.643	38.9	3770	2079
2.02	2.011	.452	18.087	37.5	2920	1606
AVERAGE				38.3		1852
STD DEV				.6		203.1
BILLET NUMBER 7						
2.009	2.008	.502	17.474	32.9	2950	1463
2.002	2.004	.502	18.067	34.2	3425	1702
2.01	2.014	.502	17.649	33.1	2950	1459
2.004	2.006	.502	17.82	33.6	3050	1514
2.001	2.006	.502	17.903	33.9	3450	1713
AVERAGE				33.5		1570
STD DEV				.54		127.2
BILLET NUMBER 8						
2.01	2.005	.501	18.28	34.5	3200	1593
2.007	2.012	.5	18.391	34.7	3075	1528
2.009	2.008	.501	18.353	34.6	3600	1789
2.008	2.004	.502	17.8355	33.6	3050	1516
2.009	2.004	.502	18.348	34.6	3550	1764
AVERAGE				34.4		1638
STD DEV				.43		130.2
BILLET NUMBER 9						
2.011	2.01	.499	16.91	31.9	2725	1358
2.01	2.01	.5	16.49	31.1	2175	1082
2.01	2.012	.5	17.08	32.2	2975	1479
2.01	2.01	.501	16.67	31.4	2350	1167
2.01	2.01	.5	17.06	32.2	3100	1542
AVERAGE				31.8		1325
STD DEV				.49		197.5

GRAND AVERAGE STRENGTH 1584
STANDARD DEVIATION 202.162

GRAND AVERAGE DENSITY 34.32
STANDARD DEVIATION 1.80527

RELATION BETWEEN STRENGTH AND DENSITY

STRENGTH = 69.7828 TIMES DENSITY (LB5/FT13) PLUS -811.866
COFF-OF CORRELATION .623149

FLEX STRENGTH AND MODULUS
ROOM TEMPERATURE TEST

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
				SPAN 8	INCHES			
10-016	.501	.501	22.03	33.4	29	2767	141	2.86
10-011	.501	.5	22.03	33.5	28	2683	138	2.82
10-009	.501	.5	21.97	33.4	29	2775	141	2.88
10-009	.5	.5	22.22	33.6	28	2688	150	3.07
10-014	.5	.501	21.94	33.3	28	2677	154	3.14
AVERAGE				33.5		2719		2.95
STD DEV				.2		49.7		.14
BILLET NUMBER 2								
				SPAN 8	INCHES			
10-021	.502	.501	22.64	34.2	32	3048	150	3.04
10-018	.499	.501	22.3	33.9	30	2874	146	2.98
10-021	.502	.5	22.51	34.1	30	2869	155	3.16
10-019	.501	.502	22.4	33.9	31	2946	164	3.31
10-024	.502	.501	22.92	34.6	33	3143	159	3.22
AVERAGE				34.2		2976		3.14
STD DEV				.31		118		.14
BILLET NUMBER 3								
				SPAN 8	INCHES			
10-02	.5	.498	21.577	32.9	31	3000	152	3.15
10-017	.5	.5	21.839	33.2	25	2400	147	3.01
10-011	.498	.5	22.161	33.9	34	3277	159	3.27
10-012	.5	.5	22.13	33.7	33	3168	152	3.11
10-013	.501	.5	22.272	33.8	32	3066	146	2.98
AVERAGE				33.5		2982		3.11
STD DEV				.41		342		.11
BILLET NUMBER 4								
				SPAN 8	INCHES			
10-001	.501	.501	23.133	35.1	25	2386	115	2.34
10-016	.501	.502	22.737	34.4	20	1901	77	1.56
9-998	.5	.502	23.036	35	28	2667	114	2.31
10-019	.501	.502	22.785	34.5	20	1901	86	1.74
9-998	.501	.502	23.111	35	27	2566	111	2.24
AVERAGE				34.8		2284		2.04
STD DEV				.34		364		.36
BILLET NUMBER 5								
				SPAN 8	INCHES			
9-968	.501	.499	22.682	34.7	22	2116	104	2.14
9-996	.5	.495	22.848	35.2	30	2938	88	1.86
9-975	.5	.5	22.946	35.1	33	3168	129	2.64
9-989	.5	.5	22.524	34.4	21	2016	80	1.64
9-985	.5	.495	22.666	34.9	23	2253	83	1.75
AVERAGE				34.8		2498		2.01
STD DEV				.33		519.9		.4
BILLET NUMBER 6								
				SPAN 8	INCHES			
10-01	.455	.503	23.304	36.8	32	3336	122	2.7
10-008	.455	.5	23.076	36.6	32	3376	129	2.9
10-016	.455	.486	22.584	36.8	27	3015	140	3.43
10-011	.455	.503	23.299	36.7	30	3127	119	2.42
10-017	.505	.455	22.709	37.6	19	2181	71	1.91
AVERAGE				36.5		3007		2.68
STD DEV				.52		485.1		.56
BILLET NUMBER 7								
				SPAN 8	INCHES			
10-045	.502	.505	22.87	34.2	30	2812	155	3.07
10-045	.502	.505	22.76	34.1	33	3093	143	2.83
10-05	.503	.505	22.96	34.3	32	2994	161	3.18
10-05	.505	.505	23.07	34.3	30	2795	158	3.11
10-04	.505	.506	23.25	34.6	32	2984	171	3.37
AVERAGE				34.3		2935		3.11
STD DEV				.18		127.7		.19
BILLET NUMBER 8								
				SPAN 8	INCHES			
10-047	.505	.505	23.53	35	32	2982	167	3.29
10-058	.505	.505	23.62	35.1	33	3075	160	3.15
10-048	.503	.505	23.55	35.2	31	2900	142	2.81
10-044	.502	.505	23.36	35	32	2999	147	2.91
10-045	.5	.505	23.11	34.7	33	3106	156	3.1
AVERAGE				35		3012		3.05
STD DEV				.17		61.1		.19
BILLET NUMBER 9								
				SPAN 8	INCHES			
9-998	.503	.501	21.09	31.9	23.5	2234	153.5	3.11
9-977	.503	.5	20.57	31.2	9.5	907	145.1	2.95
9-996	.503	.501	21.27	32.2	22.6	2145	151.6	3.07
9-975	.5	.499	20.47	31.3	17	1639	143.4	2.95
10-006	.504	.5	21.3	32.2	23	2190	149.5	3.04
AVERAGE				31.8		1823		3.02
STD DEV				.45		566.4		.07
GRAND AVERAGE STRENGTH				2693				
STANDARD DEVIATION				508.644				
GRAND AVERAGE MODULUS				279055				
STANDARD DEVIATION				50694.4				
GRAND AVERAGE DENSITY				34.46				
STANDARD DEVIATION				1.7532				

STRENGTH = 139.901 TIMES DENSITY(LBS/FT³) PLUS -2130.72
COFF.OF CORRELATION .482215

MODULUS = -6373.07 TIMES DENSITY(LBS/FT³) PLUS 498794.
COFF.OF CORRELATION -.220405

ROOM TEMPERATURE TEST
COMPRESSIVE STRENGTH AND MODULUS, VERTICAL DIRECTION

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
1.002	0.501	0.501	2.221	33.6	780	2869	71700	2.86
1.002	0.502	0.501	2.201	33.3	750	2982	71560	2.85
1.003	0.502	0.501	2.241	33.6	745	2962	69840	2.79
1.002	0.502	0.501	2.279	34.5	825	3280	76380	3.04
1.002	0.502	0.501	2.248	34	780	3101	73440	2.93
AVERAGE				33.8		3039		2.89
STD DEV				0.43		156.4		0.1
BILLET NUMBER 2								
1.003	0.502	0.501	2.29	34.6	875	3479	78600	3.13
1.003	0.502	0.498	2.303	35	805	3280	76950	3.09
1.003	0.502	0.5	2.281	34.5	750	2988	77460	3.1
1.002	0.502	0.501	2.264	34.2	750	2982	73940	2.95
1.002	0.502	0.501	2.268	34.3	745	2962	76700	3.06
AVERAGE				34.5		3126		3.06
STD DEV				0.3		223.7		0.07
BILLET NUMBER 3								
0.998	0.5	0.499	2.255	34.5	870	3487	76790	3.07
0.999	0.5	0.5	2.258	34.4	850	3400	73840	2.95
0.999	0.5	0.499	2.223	34	795	3186	73150	2.93
0.999	0.501	0.499	2.248	34.3	795	3180	74750	2.99
0.999	0.5	0.499	2.219	33.9	810	3246	73840	2.96
AVERAGE				34.2		3300		2.98
STD DEV				0.27		137		0.06
BILLET NUMBER 4								
0.998	0.5	0.501	2.326	35.4	880	3513	71490	2.85
0.998	0.5	0.5	2.287	34.9	745	2980	68600	2.74
0.998	0.5	0.499	2.308	35.3	800	3206	70000	2.8
0.998	0.501	0.499	2.335	35.7	870	3460	71450	2.85
0.998	0.501	0.5	2.337	35.6	890	3553	73190	2.92
AVERAGE				35.4		3346		2.83
STD DEV				0.3		246		0.07
BILLET NUMBER 5								
0.997	0.5	0.501	2.319	35.4	645	2575	62290	2.46
0.998	0.5	0.501	2.297	35	715	2854	71640	2.85
0.999	0.5	0.499	2.336	35.7	745	2986	74140	2.97
0.998	0.5	0.499	2.325	35.6	750	3006	61720	2.47
0.998	0.5	0.501	2.339	35.6	785	3134	67080	2.67
AVERAGE				35.5		2911		2.69
STD DEV				0.28		212.4		0.22
BILLET NUMBER 6								
0.999	0.501	0.5	2.564	39	1045	4172	86540	3.45
0.999	0.501	0.5	2.518	38.3	850	3393	75680	3.02
0.999	0.5	0.501	2.512	38.2	815	3253	74960	2.99
0.999	0.501	0.5	2.514	38.3	925	3693	75310	3
0.999	0.501	0.5	2.55	38.6	995	3972	85390	3.41
AVERAGE				38.5		3697		3.17
STD DEV				0.36		384		0.23
BILLET NUMBER 7								
1.001	0.503	0.502	2.268	34.2	605	2396	77680	3.08
1.001	0.503	0.502	2.28	34.4	560	2218	76050	3.01
1.0015	0.504	0.503	2.318	34.8	750	2958	76670	3.03
1.002	0.503	0.5014	2.292	34.6	810	3212	77040	3.06
1.0016	0.5034	0.5021	2.303	34.7	790	3126	83400	3.3
AVERAGE				34.5		2782		3.1
STD DEV				0.24		447.5		0.12
BILLET NUMBER 8								
1.002	0.5035	0.5026	2.331	35	740	2924	76670	3.04
1.0019	0.5038	0.5028	2.346	35.2	715	2883	81210	3.21
1.0018	0.504	0.5033	2.36	35.4	800	3154	77680	3.07
1.002	0.5032	0.503	2.368	35.6	780	3082	72190	2.86
1.0012	0.5032	0.5038	2.379	35.7	800	3156	90490	3.57
AVERAGE				35.4		3028		3.15
STD DEV				0.27		148.3		0.27
BILLET NUMBER 9								
0.996	0.498	0.498	2.056	31.7	690	2782	70600	2.84
0.997	0.497	0.499	2.082	32.1	740	2984	73200	2.94
0.997	0.498	0.498	2.069	31.9	660	2661	70600	2.84
0.997	0.499	0.497	2.088	32.2	630	2540	68000	2.82
0.997	0.499	0.497	2.081	32.1	650	2681	68900	2.77
AVERAGE				32		2718		2.8
STD DEV				0.18		172.5		0.12
GRAND AVERAGE STRENGTH				3105.2				
STANDARD DEVIATION				373.621				
GRAND AVERAGE MODULUS				296422				
STANDARD DEVIATION				21645.7				
GRAND AVERAGE DENSITY				34.87				
STANDARD DEVIATION				1.68823				

STRENGTH = 146.531 TIMES DENSITY (LBS/FT³) PLUS -2005.03
COFF. OF CORRELATION 0.86212

MODULUS = 4880.11 TIMES DENSITY (LBS/FT³) PLUS 126231.
COFF. OF CORRELATION 0.380622

ROOM TEMPERATURE TEST
COMPRESSIVE STRENGTH AND MODULUS, HORIZONTAL DIRECTION

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
1.002	0.501	0.501	2.227	33.7	955	3805	87440	3.49
1.002	0.502	0.501	2.211	33.4	865	3439	83580	3.33
1.002	0.501	0.501	2.271	34.4	960	3825	87310	3.49
1.002	0.502	0.501	2.271	34.3	945	3757	88930	3.54
1.002	0.501	0.501	2.186	33.1	785	3187	76600	3.14
AVERAGE				33.8		3591		3.4
STD DEV				0.56		302.4		0.17
BILLET NUMBER 2								
1.002	0.502	0.499	2.22	33.7	965	3852	90930	3.64
1.002	0.502	0.499	2.311	35.1	1010	4038	92980	3.72
1.002	0.502	0.499	2.266	34.4	905	3613	88070	3.52
1.002	0.502	0.501	2.208	33.4	845	3360	81920	3.26
1.002	0.502	0.501	2.389	36.1	910	3618	84740	3.38
AVERAGE				34.5		3695		3.5
STD DEV				1.1		256.6		0.19
BILLET NUMBER 3								
0.999	0.5	0.499	2.225	34	1005	4028	84745	3.39
0.999	0.5	0.499	2.206	33.7	960	3848	84120	3.37
0.999	0.501	0.499	2.237	34.1	980	3920	85370	3.41
0.999	0.5	0.499	2.203	33.7	965	3868	86160	3.45
0.999	0.5	0.5	2.208	33.7	955	3820	83540	3.34
AVERAGE				33.8		3897		3.39
STD DEV				0.21		82		0.04
BILLET NUMBER 4								
0.998	0.5	0.5	2.301	35.1	1020	4080	80220	3.2
0.998	0.5	0.5	2.311	35.3	1000	4000	80560	3.22
0.998	0.5	0.5	2.322	35.5	1030	4120	82180	3.28
0.998	0.5	0.5	2.335	35.7	1060	4240	83390	3.33
0.998	0.5	0.5	2.303	35.2	965	3860	81420	3.25
AVERAGE				35.3		4060		3.26
STD DEV				0.22		141.4		0.05
BILLET NUMBER 5								
0.998	0.5	0.501	2.35	35.8	860	3433	91300	3.64
0.999	0.501	0.501	2.388	36.3	1120	4462	101400	4.04
0.999	0.5	0.498	2.293	35.1	800	3213	82000	3.29
0.999	0.501	0.5	2.396	36.5	1160	4631	100000	3.99
0.999	0.5	0.5	2.302	35.1	780	3120	84760	3.39
AVERAGE				35.6		3772		3.67
STD DEV				0.64		718.7		0.34
BILLET NUMBER 6								
0.999	0.501	0.5	2.549	38.8	1255	5010	95830	3.82
0.999	0.5	0.501	2.483	37.8	1135	4531	91820	3.66
1	0.493	0.501	2.485	38.3	1215	4919	90910	3.68
0.999	0.489	0.5	2.432	37.9	1055	4315	85300	3.49
1	0.499	0.5	2.509	36.3	1140	4569	90970	3.65
AVERAGE				38.2		4669		3.66
STD DEV				0.39		288.6		0.12
BILLET NUMBER 7								
1.0019	0.5024	0.5034	2.295	34.5	855	3381	101220	4.01
1.002	0.5025	0.5024	2.314	34.9	975	3862	109850	4.36
1.0012	0.5032	0.5014	2.278	34.4	980	3884	100440	3.99
1.0018	0.5034	0.502	2.317	34.9	980	3878	104400	4.14
1.0028	0.5014	0.5022	2.281	34.4	760	3018	84750	3.38
AVERAGE				34.6		3605		3.97
STD DEV				0.84		391.5		0.37
BILLET NUMBER 8								
1.0019	0.5033	0.5011	2.317	34.9	890	3529	86920	3.45
1.0025	0.503	0.5037	2.351	35.3	955	3769	101700	4.02
1.0019	0.5043	0.5021	2.359	35.4	970	3831	86920	3.44
1.002	0.5024	0.5034	2.366	35.6	1010	3994	95020	3.76
1.0022	0.5023	0.5023	2.34	35.3	825	3270	80710	3.21
AVERAGE				35.3		3678		3.58
STD DEV				0.24		282.9		0.32
BILLET NUMBER 9								
0.998	0.499	0.498	2.076	31.9	870	3501	71600	2.88
0.998	0.5	0.501	2.063	31.4	745	2974	77400	3.08
0.998	0.5	0.498	2.094	32.1	865	3474	83400	3.34
0.997	0.5	0.499	2.065	31.8	810	3046	69900	2.75
0.998	0.5	0.501	2.127	32.4	885	3533	70900	2.82
AVERAGE				31.9		3346		2.98
STD DEV				0.38		236.4		0.24
GRAND AVERAGE STRENGTH				3812.4				
STANDARD DEVIATION				477.193				
GRAND AVERAGE MODULUS				348934				
STANDARD DEVIATION				34190.8				
GRAND AVERAGE DENSITY				34.81				
STANDARD DEVIATION				1.70857				

STRENGTH = 206.962 TIMES DENSITY (LBS/FT³) PLUS -3392.49
COFF. OF CORRELATION 0.741019

MODULUS = 10113.3 TIMES DENSITY (LBS/FT³) PLUS -3137.27
COFF. OF CORRELATION 0.505377

TENSILE STRENGTH

500 DEG TEST

ASSUME THE DENSITY IS EQUAL TO (WT/L/WT)* 2.91135

LENGTH BILLET NUMBER	WIDTH	THICK.	WEIGHT	DENSITY	LOAD	STRENGTH
BILLET NUMBER 1						
8.5	.502	.25	12.23	33.4	176	1402
8.51	.501	.251	12.47	33.9	187	1487
8.51	.502	.25	12.3	33.5	181	1442
8.52	.502	.251	12.22	33.1	178	1413
8.51	.502	.249	12.24	33.5	159	1272
AVERAGE				33.5		1403
STD DEV				.29		80.4
BILLET NUMBER 2						
8.56	.5	.249	12.43	34	183	1470
8.56	.501	.25	12.54	34.1	179	1429
8.56	.501	.251	12.61	34.1	166	1495
8.56	.499	.25	12.63	34.4	181	1451
8.55	.502	.249	12.49	34	195	1560
AVERAGE				34.1		1480
STD DEV				.19		50.4
BILLET NUMBER 3						
8.56	.502	.251	12.32	33.3	173	1373
8.56	.5	.25	12.23	33.3	191	1528
8.55	.502	.25	12.14	32.9	168	1339
8.55	.501	.25	11.75	31.9	160	1277
8.55	.501	.25	12.33	33.5	153	1222
AVERAGE				33		1347
STD DEV				.62		116.3
BILLET NUMBER 4						
8.5	.5	.251	12.64	34.5	150	1195
8.5	.5	.251	12.74	34.8	157	1251
8.51	.497	.249	12.72	35.2	177	1430
8.51	.5	.249	12.52	34.4	145	1165
8.5	.501	.249	12.7	34.9	188	1507
AVERAGE				34.7		1309
STD DEV				.3		150.9
BILLET NUMBER 5						
8.52	.494	.25	12.64	35	137	1109
8.54	.494	.249	12.64	35	110	894
8.54	.503	.251	12.4	33.5	118	935
8.54	.502	.248	12.32	33.7	113	908
8.53	.498	.249	12.18	33.5	119	960
AVERAGE				34.1		961
STD DEV				.78		86.6
BILLET NUMBER 6						
8.53	.501	.251	14.11	38.3	207	1646
8.52	.504	.251	14	37.8	176	1391
8.52	.502	.251	14.11	38.3	221	1754
8.53	.506	.249	13.64	36.9	132	1048
8.53	.503	.249	13.65	37.3	139	1110
AVERAGE				37.7		1389
STD DEV				.61		313.7
BILLET NUMBER 7						
8.5	.501	.251	12.45	33.9	182	1447
8.51	.499	.251	12.64	34.5	184	1469
8.5	.508	.251	12.63	33.9	203	1592
8.52	.505	.25	12.55	34	179	1418
8.51	.5	.251	12.56	34.2	195	1554
AVERAGE				34.1		1496
STD DEV				.27		73.8
BILLET NUMBER 8						
8.5	.507	.25	12.96	35	206	1625
8.51	.505	.248	12.9	35.2	198	1581
8.5	.5	.251	12.88	35.2	192	1530
8.49	.505	.251	12.79	34.6	201	1588
8.5	.493	.251	12.62	34.9	177	1430
AVERAGE				35		1550
STD DEV				.25		75.2
BILLET NUMBER 9						
8.52	.502	.246	11.767	32.6	75	607
8.52	.497	.248	11.351	31.5	70	566
8.52	.497	.249	11.723	32.4	105	848
8.52	.496	.249	11.602	31.6	105	830
AVERAGE				32.1		718
STD DEV				.5		151.9

GRAND AVERAGE STRENGTH 1308.4
STANDARD DEVIATION 281.91

GRAND AVERAGE DENSITY 34.31
STANDARD DEVIATION 1.53559
RELATION BETWEEN STRENGTH AND DENSITY

STRENGTH = 78.3517 TIMES DENSITY(LBS/FT³) PLUS -1379.95
COEFF. OF CORRELATION .426788

SHEAR STRENGTH
500 DEG TEST

LENGTH	WIDTH	THICK.	WEIGHT	DENSITY	LOAD	STRENGTH
BILLET NUMBER 1						
2.011	2.016	.503	18.07	33.8	2770	1366
2.011	2.01	.503	17.93	33.6	2540	1256
2.011	2.011	.503	17.99	33.7	2305	1139
2.011	2.011	.503	17.98	33.7	2455	1214
AVERAGE				33.7		1243
STD DEV				.07		94.6
BILLET NUMBER 2						
2.011	2.011	.502	18.14	34	1770	877
2.011	2.011	.502	18.15	34.1	1845	914
2.011	2.011	.502	18.11	34	2085	1033
2.011	2.011	.502	18.16	34.1	2675	1325
AVERAGE				34		1037
STD DEV				.04		203.1
BILLET NUMBER 3						
2.013	2.011	.502	17.62	33	2020	1000
2.007	2.008	.502	17.77	33.5	2000	992
2.008	2.008	.502	17.92	33.7	2025	1004
2.013	2.009	.502	17.66	33.1	2235	1108
2.004	2.007	.502	18.15	34.2	2175	1079
AVERAGE				33.5		1036
STD DEV				.49		53.1
BILLET NUMBER 4						
2.011	2.012	.502	18.898	35.4	2465	1220
2.015	2.009	.502	18.5	34.7	2405	1192
2.009	2.012	.502	18.593	34.9	2575	1275
2.009	2.012	.502	18.877	35.4	3120	1545
2.009	2.012	.502	18.565	34.9	2615	1295
AVERAGE				35.1		1305
STD DEV				.35		139.9
BILLET NUMBER 5						
2.015	2.011	.502	18.921	35.4	1920	951
2.006	2.016	.502	18.828	35.3	2955	1460
2.015	2.011	.502	18.412	34.5	1890	936
2.011	2.018	.502	18.998	35.5	2810	1367
2.011	2.013	.498	18.107	34.2	2070	1032
AVERAGE				35		1153
STD DEV				.6		250.7
BILLET NUMBER 6						
2.014	2.01	.452	18.338	38.2	2360	1299
2.009	2.011	.452	18.55	38.7	2475	1361
2.011	2.02	.452	18.031	37.4	2305	1262
2.016	2.007	.452	18.571	38.7	2175	1199
2.005	2.014	.452	18.625	38.9	2330	1280
AVERAGE				38.4		1280
STD DEV				.6		58.9
BILLET NUMBER 7						
2.004	2.004	.501	18.365	34.8	2180	1066
2.009	2.008	.501	18.47	34.8	2565	1275
2.003	2.008	.501	18.394	34.8	2770	1377
2.008	2.009	.501	18.267	34.4	1865	926
2.006	2.006	.501	18.39	34.8	2575	1281
AVERAGE				34.7		1188
STD DEV				.16		180.8
BILLET NUMBER 8						
2.011	2.007	.501	18.623	35.1	2095	1042
2.007	2.005	.501	18.512	35	2065	1028
2.011	2.005	.501	18.245	34.4	2415	1202
2	2.006	.501	18.412	34.9	2450	1219
2.011	2.004	.501	18.569	35	2350	1170
AVERAGE				34.9		1132
STD DEV				.27		90.7
BILLET NUMBER 9						
2.01	2.01	.5	16.415	31	1565	779
2.008	2.007	.498	16.93	32.1	2430	1214
2.013	2.013	.5	16.54	31.1	1975	981
2.015	2.015	.5	17.07	32	1465	727
2.01	2.01	.498	16.74	31.7	1890	944
AVERAGE				31.6		989
STD DEV				.54		192.7

GRAND AVERAGE STRENGTH 1145.4
STANDARD DEVIATION 184.191

GRAND AVERAGE DENSITY 34.57
STANDARD DEVIATION 1.79481

RELATION BETWEEN STRENGTH AND DENSITY

STRENGTH = 54.2457 TIMES DENSITY(LBS/FT³) PLUS -730.068
COFF.OF CORRELATION .528408

500 DEG F TEST
FLEX STRENGTH AND MODULUS

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
				SPAN 8	INCHES			
10-026	.501	.501	22.37	33.9	22	2099	116	2.36
10-016	.5	.502	22.36	33.9	27	2571	118	2.39
10-011	.501	.5	22.26	33.8	26	2491	115	2.35
10-014	.501	.501	22.4	34	27	2577	111	2.26
10-012	.5	.5	22.05	33.6	23	2208	122	2.5
AVERAGE				33.8		2389		2.37
STD DEV				.15		221.1		.09
BILLET NUMBER 2								
				SPAN 8	INCHES			
10-017	.5	.502	22.32	33.8	24	2286	120	2.43
10-014	.5	.501	22.68	34.4	27	2582	129	2.63
10-012	.5	.502	22.86	34.7	26	2476	119	2.41
10-02	.501	.502	22.5	34	25	2376	128	2.59
10-019	.501	.501	22.37	33.9	25	2386	122	2.48
AVERAGE				34.2		2421		2.51
STD DEV				.37		112.3		.1
BILLET NUMBER 3								
				SPAN 8	INCHES			
10-017	.5	.502	21.681	32.9	25	2381	123	2.49
10-005	.502	.501	22.351	33.8	23	2190	127	2.58
10-017	.502	.502	22.002	33.8	23	2182	130	2.62
10-011	.501	.5	22.388	33.9	24	2299	132	2.7
10-017	.5	.501	21.803	33.1	23	2199	121	2.46
AVERAGE				33.4		2250		2.57
STD DEV				.47		87.1		.1
BILLET NUMBER 4								
				SPAN 8	INCHES			
10-011	.501	.503	22.783	34.4	17	1609	62	1.24
10-017	.5	.504	22.737	34.3	16	1512	63	1.26
10-009	.5	.501	22.723	34.5	19	1817	71	1.45
10-003	.501	.5	23.22	35.3	22	2108	85	1.74
10	.501	.5	23.072	35.1	20	1916	93	1.9
AVERAGE				34.7		1792		1.52
STD DEV				.44		238.6		.29
BILLET NUMBER 5								
				SPAN 8	INCHES			
9-998	.501	.494	22.865	35.2	20	1963	81	1.72
9-999	.5	.5	22.815	34.8	22	2112	88	1.8
10	.501	.494	22.735	35	25	2454	86	1.82
9-993	.501	.491	22.754	35.3	20	1987	88	1.9
9-996	.501	.494	22.484	34.6	18	1767	82	1.74
AVERAGE				35		2056		1.8
STD DEV				.27		254.2		.07
BILLET NUMBER 6								
				SPAN 8	INCHES			
10-016	.455	.503	22.674	37.7	22	2293	73	1.61
10-018	.502	.455	23.579	39.3	23	2656	86	2.33
10-017	.455	.505	22.689	37.6	20	2068	60	1.31
10-018	.503	.455	23.159	38.4	23	2639	77	2.07
10-017	.504	.455	22.729	37.7	19	2185	71	1.91
AVERAGE				38.1		2368		1.85
STD DEV				.73		266.9		.4
BILLET NUMBER 7								
				SPAN 8	INCHES			
10-034	.504	.504	23.06	34.5	25	2343	135	2.68
10-038	.503	.504	22.93	34.3	29	2724	127	2.52
10-045	.498	.504	22.41	33.9	26	2466	120	2.41
10-042	.501	.505	23.18	34.8	29	2724	132	2.60
10-052	.502	.503	23.19	34.6	28	2645	133	2.66
AVERAGE				34.4		2581		2.58
STD DEV				.38		169.2		.11
BILLET NUMBER 8								
				SPAN 8	INCHES			
10-043	.502	.505	23.53	35.2	28	2625	124.5	2.46
10-046	.504	.505	23.51	35	28	2614	129	2.54
10-065	.503	.504	23.34	34.9	28	2630	123	2.44
10-069	.503	.505	23.65	35.2	28	2619	122	2.41
10-071	.504	.505	23.605	35.1	28	2614	120	2.37
AVERAGE				35.1		2620		2.45
STD DEV				.15		6.8		.07
BILLET NUMBER 9								
				SPAN 8	INCHES			
9-983	.503	.5	20.48	31.1	10.5	1002	116	2.36
10	.503	.5	21.16	32.1	12	1145	123	2.5
9-981	.503	.499	20.56	31.3	10	998	115	2.36
9-996	.503	.5	21.24	32.2	12	1145	123	2.5
9-991	.503	.5	20.61	31.3	10.5	1002	124	2.52
AVERAGE				31.6		1050		2.45
STD DEV				.51		88.3		.08
GRAND AVERAGE STRENGTH				2169.9				
STANDARD DEVIATION				497.23				
GRAND AVERAGE MODULUS				223101				
STANDARD DEVIATION				41397.5				
GRAND AVERAGE DENSITY				34.48				
STANDARD DEVIATION				1.70085				

STRENGTH = 160.858 TIMES DENSITY(LBS/FT³) PLUS -3376.09
COEFF. OF CORRELATION .550236

MODULUS = -9791.71 TIMES DENSITY(LBS/FT³) PLUS 560695.
COEFF. OF CORRELATION -.402299

500 DEG TEST
COMPRESSIVE STRENGTH AND MODULUS, VERTICAL DIRECTION

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
1.003	0.508	0.501	2.201	33.8	980	2306	37460	1.49
1.003	0.508	0.501	2.236	33.8	615	2445	37140	1.48
1.003	0.502	0.501	2.186	33	655	2604	38570	1.54
1.002	0.502	0.501	2.245	33.9	645	2644	37690	1.5
1.003	0.502	0.501	2.229	33.7	605	2406	36580	1.46
AVERAGE				33.5		2481		1.49
STD DEV				0.38		140.9		0.03
BILLET NUMBER 2								
1.003	0.502	0.498	2.333	35.4	670	2680	40070	1.61
1.002	0.502	0.5	2.3	34.8	670	2669	39110	1.56
1.002	0.502	0.5	2.278	34.5	635	2530	39020	1.56
1.002	0.502	0.501	2.288	34.6	675	2684	38930	1.55
1.003	0.502	0.499	2.304	34.9	630	2515	38740	1.55
AVERAGE				34.9		2616		1.57
STD DEV				0.37		85.4		0.02
BILLET NUMBER 3								
0.999	0.5	0.5	2.227	34	635	2540	37090	1.48
0.999	0.501	0.499	2.25	34.3	650	2600	40870	1.63
0.999	0.501	0.499	2.214	33.8	615	2460	38110	1.52
0.999	0.5	0.5	2.223	33.9	650	2600	39630	1.58
0.999	0.501	0.499	2.177	33.2	670	2680	40465	1.62
AVERAGE				33.8		2576		1.57
STD DEV				0.41		81.7		0.06
BILLET NUMBER 4								
0.998	0.5	0.5	2.302	35.2	595	2380	38890	1.55
0.998	0.501	0.5	2.296	35	605	2415	39960	1.59
0.998	0.5	0.5	2.348	35.9	680	2720	40650	1.62
0.998	0.5	0.5	2.329	35.6	690	2780	41530	1.66
0.998	0.501	0.5	2.313	35.3	675	2695	42130	1.68
AVERAGE				35.4		2594		1.62
STD DEV				0.35		181.2		0.05
BILLET NUMBER 5								
0.998	0.5	0.501	2.306	35.1	630	2515	37870	1.51
0.999	0.501	0.5	2.32	35.3	700	2794	41610	1.66
0.997	0.5	0.499	2.265	34.7	640	2565	36585	1.46
0.998	0.5	0.501	2.318	35.3	650	2595	39000	1.55
0.999	0.501	0.499	2.3	35.1	620	2480	37233	1.49
AVERAGE				35.1		2590		1.53
STD DEV				0.26		122.6		0.08
BILLET NUMBER 6								
0.999	0.501	0.5	2.518	38.3	680	2715	40650	1.62
0.999	0.501	0.501	2.519	38.3	670	2669	40440	1.61
0.999	0.501	0.5	2.517	38.3	695	2774	40480	1.61
0.999	0.5	0.5	2.533	38.6	745	2980	39630	1.58
0.999	0.501	0.501	2.518	38.3	645	2570	39020	1.55
AVERAGE				38.4		2742		1.6
STD DEV				0.16		152.8		0.03
BILLET NUMBER 7								
1.0011	0.5019	0.5028	2.281	34.4	580	2298	36590	1.45
1.001	0.5035	0.5019	2.311	34.8	605	2394	37940	1.5
1.0017	0.5034	0.5027	2.28	34.3	606	2395	37230	1.47
0.9995	0.5035	0.5018	2.309	34.8	600	2375	39020	1.54
1.0018	0.504	0.5026	2.326	34.9	625	2467	38800	1.53
AVERAGE				34.6		2386		1.5
STD DEV				0.29		60.3		0.04
BILLET NUMBER 8								
1.0039	0.5048	0.5039	2.34	34.9	595	2339	38110	1.5
1.0048	0.5048	0.5037	2.363	35.3	670	2635	40340	1.59
1.0042	0.5041	0.5039	2.37	35.4	715	2815	44130	1.74
1.0028	0.5035	0.5033	2.378	35.7	655	2585	38510	1.52
1.0041	0.5044	0.504	2.351	35.1	640	2516	40172	1.59
AVERAGE				35.3		2578		1.59
STD DEV				0.28		173.3		0.09
BILLET NUMBER 9								
0.998	0.5	0.498	2.063	31.6	625	2510	39000	1.56
0.998	0.499	0.499	2.069	31.7	400	1606	26700	1.07
0.998	0.5	0.499	2.091	32	610	2445	41500	1.66
0.997	0.5	0.499	2.071	31.7	580	2084	39500	1.58
0.998	0.5	0.499	2.071	31.7	560	2244	40400	1.62
AVERAGE				31.6		2178		1.5
STD DEV				0.14		361		0.24
GRAND AVERAGE STRENGTH				2526.7				
STANDARD DEVIATION				220.136				
GRAND AVERAGE MODULUS				155210				
STANDARD DEVIATION				9814.94				
GRAND AVERAGE DENSITY				34.75				
STANDARD DEVIATION				1.71457				

STRENGTH = 79.8002 TIMES DENSITY(LBS/FT³) PLUS -246.261
COEFF OF CORRELATION 0.621539

MODULUS = 1848.41 TIMES DENSITY(LBS/FT³) PLUS 90980.
COEFF OF CORRELATION 0.322899

500 DEG TEST
COMPRESSIVE STRENGTH AND MODULUS, HORIZONTAL DIRECTION

LEN IN	WID IN	THICK IN	WT GRAM	DEN PCF	LOAD LBS	STR PSI	SLOPE LBS/IN	MOD X10 ⁵
BILLET NUMBER 1								
1.008	0.508	0.501	8.8	33.3	780	8863	41080	1.64
1.008	0.501	0.5	8.84	34	715	8854	40000	1.6
1.003	0.501	0.501	8.844	34	805	3807	44800	1.79
1.008	0.501	0.5	8.846	34.1	680	8715	34910	1.4
1.003	0.508	0.508	8.817	33.4	660	8619	38110	1.58
AVERAGE					33.7	8652		1.59
STD DEV					0.38	223.3		0.15
BILLET NUMBER 2								
1.008	0.508	0.499	8.315	35.1	815	3254	46070	1.84
1.008	0.508	0.498	8.298	34.9	810	3240	46340	1.86
1.008	0.508	0.5	8.294	34.8	775	3088	44620	1.78
1.001	0.501	0.5	8.291	34.8	770	3074	43000	1.72
1.008	0.508	0.501	8.375	35.9	780	3101	44170	1.76
AVERAGE					35.1	3151		1.79
STD DEV					0.48	87.8		0.06
BILLET NUMBER 3								
0.998	0.5	0.499	8.148	38.8	645	2585	41610	1.66
0.999	0.5	0.5	8.214	33.8	745	2980	45820	1.83
0.999	0.5	0.499	8.213	33.8	705	2826	43760	1.75
0.999	0.5	0.499	8.223	34	775	3106	46280	1.85
0.998	0.5	0.5	8.223	33.9	695	2780	43290	1.73
AVERAGE					33.7	2855		1.77
STD DEV					0.5	198.8		0.08
BILLET NUMBER 4								
0.998	0.5	0.501	8.301	35.1	855	3413	45820	1.83
0.998	0.5	0.5	8.262	34.5	730	2980	42820	1.71
0.998	0.499	0.5	8.323	35.5	790	3166	45910	1.84
0.998	0.5	0.5	8.343	35.8	855	3420	46900	1.87
0.998	0.499	0.499	8.265	34.7	665	2671	38910	1.56
AVERAGE					35.1	3118		1.76
STD DEV					0.53	324		0.13
BILLET NUMBER 5								
0.999	0.5	0.502	8.397	36.4	880	3267	51830	2.06
0.999	0.5	0.5	8.307	35.2	730	2920	42970	1.72
1	0.501	0.499	8.403	36.6	1060	4840	51990	2.08
0.998	0.499	0.5	8.223	34	635	2545	41720	1.67
0.998	0.5	0.499	8.291	35.1	630	2525	40240	1.61
AVERAGE					35.5	3099		1.83
STD DEV					1.07	706.8		0.23
BILLET NUMBER 6								
1	0.5	0.5	8.521	38.4	935	3740	48780	1.95
1	0.5	0.5	8.548	38.8	940	3760	46800	1.87
0.999	0.5	0.5	8.488	38	795	3180	44930	1.8
0.999	0.49	0.5	8.501	38.9	955	3898	48155	1.96
1	0.5	0.5	8.563	39.1	1015	4060	50100	2
AVERAGE					38.6	3728		1.92
STD DEV					0.45	331.9		0.08
BILLET NUMBER 7								
1.004	0.5012	0.5013	8.258	34.2	680	2468	40396	1.61
1.003	0.5021	0.5012	8.293	34.6	690	2742	43900	1.75
1.0019	0.503	0.5015	8.313	34.9	760	3013	47560	1.89
1.0022	0.5029	0.5018	8.293	34.5	820	3249	48780	1.94
1.0028	0.5026	0.5018	8.268	34.8	625	2478	43150	1.72
AVERAGE					34.5	2790		1.78
STD DEV					0.89	340.7		0.13
BILLET NUMBER 8								
1.0042	0.5049	0.504	2.336	34.9	785	3085	45500	1.8
1.0038	0.5045	0.5023	2.369	35.5	810	3196	45730	1.81
1.0039	0.5035	0.5044	2.351	35.1	810	3189	49390	1.95
1.0043	0.5049	0.5024	2.358	35.3	800	3154	47420	1.88
1.0044	0.5024	0.5034	2.338	35	700	2768	46560	1.85
AVERAGE					35.1	3078		1.86
STD DEV					0.24	179.2		0.06
BILLET NUMBER 9								
0.997	0.5	0.5	8.042	31.2	710	2840	44700	1.78
0.998	0.5	0.498	8.094	32.1	780	2892	46000	1.84
0.997	0.501	0.499	8.056	31.4	715	2860	47300	1.89
0.999	0.5	0.497	8.127	32.6	740	2976	46700	1.88
0.997	0.499	0.498	8.076	31.9	595	2394	40000	1.61
AVERAGE					31.9	2793		1.8
STD DEV					0.57	228.9		0.11
GRAND AVERAGE STRENGTH				3051.6				
STANDARD DEVIATION				412.608				
GRAND AVERAGE MODULUS				178765				
STANDARD DEVIATION				14135.8				
GRAND AVERAGE DENSITY				34.8				
STANDARD DEVIATION				1.80918				

STRENGTH = 168.87 TIMES DENSITY(LBS/FT³) PLUS -2825.53
COFF.OF CORRELATION 0.740454

MODULUS = 3555.5 TIMES DENSITY(LBS/FT³) PLUS 86024.
COFF.OF CORRELATION 0.455038

APPENDIX B

COEFFICIENT OF CORRELATION BETWEEN 18 TEST PROPERTIES

APPENDIX B

Coefficient of Correlation Between 18 Test Properties

Key

- 1 RT Tensile Strength
- 2 RT Shear Strength
- 3 RT Flexure Strength
- 4 RT Flexure Modulus
- 5 RT Compressive Strength, Vertical
6. RT Compressive Strength, Horizontal
7. RT Compressive Modulus, Vertical
8. RT Compressive Modulus, Horizontal
9. 500°F Tensile Strength
10. 500°F Shear Strength
11. 500°F Flexure Strength
12. 500°F Flexure Modulus
13. 500°F Compressive Strength, Vertical
14. 500°F Compressive Strength, Horizontal
15. 500°F Compressive Modulus, Vertical
16. 500°F Compressive Modulus, Horizontal
17. Water Adsorption (1 hr water boil)
18. Heat Distortion Temperature 264 psi

Note: Nos. 1 through 16; the property has been corrected for density using least square line method.

	1	2	3	4	5	6	7	8	9
1	1	0.48	0.82	0.35	-0.13	-0.34	0.52	0.79	0.87
2	0.48	1	0.75	0.77	0.58	0.32	0.78	0.14	0.8
3	0.82	0.75	1	0.69	0.15	-0.05	0.73	0.65	0.85
4	0.35	0.77	0.69	1	0.15	0.02	0.94	0.3	0.58
5	-0.13	0.58	0.15	0.15	1	0.9	0.1	-0.53	0.22
6	-0.34	0.32	-0.05	0.02	0.9	1	-0.09	-0.52	-0.07
7	0.52	0.78	0.73	0.94	0.1	-0.09	1	0.37	0.73
8	0.79	0.14	0.65	0.3	-0.53	-0.52	0.37	1	0.5
9	0.87	0.8	0.85	0.58	0.22	-0.07	0.73	0.5	1
10	0.38	-0.03	-0.04	-0.34	-0.02	-0.09	-0.23	0.15	0.32
11	0.94	0.63	0.94	0.54	-0.04	-0.27	0.62	0.76	0.88
12	0.49	0.68	0.8	0.96	0	-0.1	0.9	0.53	0.59
13	0.46	0.49	0.56	0	0.54	0.31	0.05	0.07	0.49
14	-0.39	0.25	-0.15	0.12	0.38	0.28	-0.01	-0.49	-0.24
15	0.02	0.25	0.03	-0.07	0.59	0.42	0.1	-0.45	0.21
16	-0.24	-0.24	-0.11	0.17	-0.26	-0.14	0.16	-0.01	-0.34
17	-0.29	-0.29	-0.4	-0.48	0.03	0.05	-0.36	-0.34	-0.16
18	0.65	0.72	0.75	0.45	0.4	0.1	0.58	0.23	0.87

	10	11	12	13	14	15	16	17	18
1	0.38	0.94	0.49	0.46	-0.39	0.02	-0.24	-0.29	0.65
2	-0.03	0.63	0.68	0.49	0.25	0.25	-0.24	-0.29	0.72
3	-0.04	0.94	0.8	0.56	-0.15	0.03	-0.11	-0.4	0.75
4	-0.34	0.54	0.96	0	0.12	-0.07	0.17	-0.48	0.45
5	-0.02	-0.04	0	0.54	0.38	0.59	-0.26	0.03	0.4
6	-0.09	-0.27	-0.1	0.31	0.28	0.42	-0.14	0.05	0.1
7	-0.23	0.62	0.9	0.05	-0.01	0.1	0.16	-0.36	0.58
8	0.15	0.76	0.53	0.07	-0.49	-0.45	-0.01	-0.34	0.23
9	0.32	0.88	0.59	0.49	-0.24	0.21	-0.34	-0.16	0.87
10	1	0.23	-0.36	0.04	-0.49	-0.17	-0.81	0.29	0.26
11	0.23	1	0.67	0.51	-0.28	-0.09	-0.27	-0.35	0.73
12	-0.36	0.67	1	0.06	0	-0.17	0.22	-0.56	0.43
13	0.04	0.51	0.06	1	0.24	0.52	-0.22	-0.15	0.57
14	-0.49	-0.28	0	0.24	1	0.3	0.32	-0.44	-0.31
15	-0.17	-0.09	-0.17	0.52	0.3	1	0.25	0.07	0.3
16	-0.81	-0.27	0.22	-0.22	0.32	0.25	1	-0.42	-0.46
17	0.29	-0.35	-0.56	-0.15	-0.44	0.07	-0.42	1	0.18
18	0.26	0.73	0.43	0.57	-0.31	0.3	-0.46	0.18	1

APPENDIX C

MATERIAL SPECIFICATION: IMIDITE 2801 PREPOLYMER

APPENDIX C

Material Specification: IMIDITE 2801 Prepolymer

Qualified Vendor: Whittaker Corporation, Narmco Materials Division
(NMD), Costa Mesa, California

1. Material Requirements

- 1.1 Composition: The material shall be a condensation prepolymer based on 3,3'-diaminobenzidine and diphenyl isophthalate.
- 1.2 Raw Materials: Only quality raw materials shall be used for manufacture of prepolymer. A record of lot numbers and incoming inspection results shall be kept on each raw material used for prepolymers purchased under this specification.
- 1.3 Form: The material shall be a ground powder, uniform in quality and free of foreign materials. Sieve analyses conducted in accordance with paragraph 5.1 shall show a maximum of 0.5% retained on a 50 mesh sieve; a maximum of 25% retained on a 100 mesh sieve; and a minimum of 13% passing through a 200 mesh sieve.
- 1.4 Color: The material shall be light tan in color. The material shall have a maximum color index of 0.40 when tested in accordance with paragraph 5.7.
- 1.5 Melting Point: The material shall have an initial melting point of 83°-109°C, and a final melting point of 115° to 135°C when tested in accordance with paragraph 5.2.
- 1.6 Volatile Content: The volatile content shall be 23 to 29% when tested in accordance with paragraph 5.3.
- 1.7 Bond Strength: Bonds prepared and tested in accordance with paragraph 5.4 shall have a minimum bond strength of 3000 psi when tested at room temperature, and 2300 psi when tested at 700°F.
- 1.8 Insolubles: Insoluble material shall be less than 0.1% when tested in accordance with paragraph 5.8.

2. Vendor Certification

- 2.1 The vendor shall certify that the material supplied under this specification is capable of meeting the requirements of Section 1 for a period of 90 days after the date of shipment; provided that storage is below 75°F in an opaque, air tight container.
- 2.2 The statement of conformity shall include material designation, batch number, quantity of material supplied, manufacturing date, warranty expiration date, WRD order number, melting point, RT bond strength, and 700°F bond strength.

3. Packaging

3.1 The material shall be supplied in opaque, air-tight containers. Each container shall be marked with the following information:

- a. Manufacturer's name
- b. Product name and number
- c. Batch number
- d. Date of manufacture
- e. Warranty expiration date
- f. Net weight

4. WRD Receiving Inspection

4.1 A visual inspection of the material shall indicate conformity to the requirement of this specification.

4.2 The total net weight of the material (including back-ordered material) shall be as specified on the purchase order.

4.3 A capillary tube melting point shall be determined on each lot of material received. This melting point shall be in agreement with paragraph 1.5 and in general agreement with the melting point reported by the vendor.

4.4 Receiving inspection shall select one of the following tests to be run on each shipment:

- a. Sieve analysis per paragraph 1.3
- b. TGA weight loss in nitrogen per paragraph 5.6
- c. TGA weight loss in air per paragraph 5.6
- d. Infrared spectra per paragraph 5.5
- e. Color index per paragraph 5.7

4.5 Material which meets the requirements of this specification shall be so identified and released for production use.

5. Test Procedures

5.1 Sieve Analysis: Place 100 gm into the top of a stack of full-size, 8-inch diameter standard sieves; stacking order from the top shall be: cover, 50 mesh, 100 mesh, 150 mesh, 200 mesh, 250-mesh, pan. Shake for 1 hour on a Cenco-Meinzner Sieve shaker at a setting of 8. Determine the weight gain of each sieve and pan. Report as percent weight retained by each mesh.

5.2 Melting Point: The melting point shall be determined, using a standard capillary tube method, by experienced personnel. The initial, resin, and final melting points shall be determined and recorded.

- 5.3 Volatile Content: The volatile content shall be determined in accordance with NMD-SOP-QC-CT-26 summarized as follows: A 2.6 ± 0.3 gm sample in a test tube is heated to $350 \pm 5^\circ\text{C}$ for 12 ± 2 minutes at atmospheric pressure; the sample is held at $350 \pm 5^\circ\text{C}$ for 2 hours under full vacuum; the average percent weight-loss of two determinations shall be calculated; the average deviation of the mean shall not exceed 0.4.

$$\text{A.D.} = \frac{\sum (X - \bar{X})}{N}$$

- 5.4 Bond Strength: A solution of 10 gm prepolymer, 20 ml of reagent grade pyridine and 10 gm of MD-105 aluminum powder shall be prepared per NMD-SOP-QC-PT-6.

This solution shall be used to prepare 17-7 PH stainless steel bonds with 112-A-1100E glass cloth scrim per NMD-SOP-QC-SP-12.

Bonds shall be tested at room temperature and at 700°F in accordance with NMD-SOP-QC-MT-8.

- 5.5 Infrared Spectra: Prepare a KBr pellet with dry spectro grade KBr and 250 mesh prepolymer. The spectra shall agree with the reference spectra in WRD Notebook AHM-02147-Page 4.

- 5.6 TGA Analysis: TGA analysis shall be run on a Dupont thermal analyzer. Sample shall be 10 to 12 mg of 250 mesh prepolymer. Heating rate shall be 5 degrees/min. Gas flow rate shall be 0.075 CFM.

Using nitrogen gas, the TGA curve shall show a weight loss of 22 to 30% at 375°C , and a weight loss of less than 50% at 800°C .

Using air as the purge gas, the TGA shall show a weight loss of 22 to 30% at 375°C , and a slope intercept polymer decomposition temperature of 530°C - 600°C .

- 5.7. Color Test: Weigh a 67-100 mg sample of 200 mesh IMIDITE 2801 prepolymer into a 50 ml stoppered flask. Add $[0.500 \times \text{sample weight (mg)}]$ ml ± 1 ml of spectrograde acetone. Shake vigorously for exactly two minutes. Immediately filter the solution through a coarse filter paper, collecting about 10 ml of filtrate.

Dilute 1.00 ml of this solution to 100 ml with additional acetone.

Determine the adsorbance of the dilute solution at $343 \text{ m}\mu$ and the adsorbance of the undiluted solution at $435 \text{ m}\mu$, using acetone as a reference in each case

$$\text{Color index} = \frac{(\text{Adsorbance of concentrated solution at } 435 \text{ m}\mu)}{(\text{Adsorbance of dilute solution at } 343 \text{ m}\mu)}$$

Note: The entire procedure should be completed in minimum time because the color is time dependent.

5.8 Insolubles: Weigh a 20 gram sample of prepolymer into an extracted, dried and weighed 33 X 94 mm soxhlet extractor thimble. Extract the prepolymer in a soxhlet extractor, using pyridine solvent, until the discharge liquid is clear. Continue extraction for an additional 1 hour. Dry the thimble and reweigh.

$$\text{Insolubles (percent)} = \left(\frac{\text{Weight of residue}}{\text{Weight of sample}} \right) (100)$$

APPENDIX D

MATERIAL SPECIFICATION: ECGOSPHERES Si

APPENDIX D

Material Specification: Eccospheres Si

Qualified Vendor: Emerson & Cuming, Inc., Canton, Mass.

1. Material Requirements

1.1 Average True Particle Density (Test 5.1)

The material shall exhibit an average true particle density of less than 0.290.

1.2 Chemical Composition (Test 5.2)

The material shall have a composition of minimum 92% silica.

1.3 Sieve Analysis (Test 5.3)

The material shall pass through a 60 mesh screen, not more than 0.5% shall be retained. There shall be no foreign materials retained.

1.4 Moisture Content (Test 5.4)

The material shall have a moisture content of 0.8% maximum.

1.5 Alkalinity (Test 5.5)

The alkalinity of the material shall be 1.2 meq/gm max.

2. Vendor Certification

2.1 The vendor shall certify that the material supplied under the specification meets the requirements of this specification.

2.2 The statement of conformity shall include material designation, lot number, true particle density and WRD order number.

3. Packaging

3.1 The material shall be packaged in a sealed Fiber-pack or metal container(s). Each container shall contain the following information:

- a. Manufacturer's name
- b. Product designation
- c. Lot number
- d. Net weight

4. WRD Receiving Inspection

- 4.1 A visual inspection of the material shall indicate conformity to the requirements of this specification.
- 4.2 The total net weight of the material (including back ordered material) shall be as specified on the purchase order.
- 4.3 The bulk density of the material shall be less than 0.18 gm/cc when tested per paragraph 5.6.
- 4.4 Eccospheres Si which meet the requirements of this specification shall be as identified and released for production use.

5. Test Procedures

5.1 True Particle Density

Average true particle density shall be determined by a gas displacement method.

5.2 Chemical Composition

No specific method required. Verification from vendor that the material is SiO_2 of not less than 92% will be adequate.

5.3 Sieve analysis shall be determined by the following method:

One hundred grams of representative sample shall be shaken, using a Cenco-Meiner shaker set at "7" speed.

Sample shall be shaken for 20 minutes.

Sieve analysis shall be a measure of the weight percent retained.

5.4 Water content shall be determined by the following method:

Heat a clean 100-ml platinum dish in a drying oven for 2 hours at $250 \pm 5^\circ\text{F}$. Remove the dish and cool in a desiccator. Tare the dish.

To the platinum dish add an approximate 10-gram microballoon sample, accurately weighed, to the nearest milligram.

Place the sample and dish in the drying oven for 2 hours at $250 \pm 5^\circ\text{F}$. Remove from oven, cool to room temperature in a desiccator, then weigh.

Calculation

$$\text{Percent Water} = \frac{W - B \times 100}{W}$$

Where W = original weight of sample.

B = sample weight after drying

5.5 Alkalinity shall be determined in the following manner:

Weigh a sample of approximately 2 grams to the nearest milligram.

Digest sample in 100 ml of distilled water for 2 hours at 90°C to 98°C using a 250-cc beaker with a watch-glass cover and a magnetic stirrer hot plate with teflon-coated stirring rod.

$$\text{Meq/gm.} = \frac{\text{milliliters of HCl times normality}}{\text{Weight of sample (grams)}}$$

5.6 Bulk density shall be determined as follows.

Fill a weighed 250 ml graduate cylinder to the 250-ml mark using maximum hand packing.

$$\text{Bulk Density} = \frac{\text{Change in weight in grams}}{250}$$

APPENDIX E

MATERIAL SPECIFICATION: KAOWOOL CERAMIC FIBER (BULK A)

APPENDIX E

Material Specification: Kaowool Ceramic Fiber (Bulk A)

Qualified Vendor: Babcock & Wilcox Company, Refractories Division

1. Material Requirements

- 1.1 Composition: The material shall be silica-alumina ceramic fibers with a minimum silica content of 50%. Typical analysis shall be:

Al_2O_3	45.1%
SiO_2	51.9%
Fe_2O_3	1.3%
TiO_2	1.7%
MgO	Trace
CaO	0.1%
Alkalies as Na_2O	0.2%
B_2O_3	0.08%

- 1.2 Form: The material shall consist of random-length fibers. Typical fiber length shall be 4 inches and typical fiber diameter shall be 2.8 microns. The maximum fiber diameter shall be 3.0 microns, using Method 5.1

- 1.3 Appearance: The material shall be white bulk fibers that are uniform in quality, clean and free from foreign material and stains.

- 1.4 The material shall be lubricated to permit ease of handling. The lubricant shall be completely removed by heating to 1000°F.

- 1.5 Typical properties of the material shall include:

Specific Gravity	2.56
Specific Heat at 1800°F mean	0.255 Btu/lb/F
Tensile Strength, Fiber	1.9×10^5 lb/sq. in.
Tensile Modulus, Fiber	16.8×10^6 lb/sq. in.
Packing Density	To 12 lb/cu. ft.
Continuous Use Temperature	To 2300°F
Melting point	3200°F
Hardness:	6-MOH's scale
	700-Knoop scale 100 g loading

2. Vendor Certification

2.1 The Vendor shall certify that the material supplied under this specification meets the requirements of Section 1.

3. Packaging

3.1 The material shall be supplied in sealed containers. Each container shall contain the following information.

- a. Manufacturer's Name
- b. Product name and type
- c. Batch or control number
- d. Net weight

4. WRD Receiving Inspection

4.1 A visual inspection of the material shall indicate conformity to the requirements of this inspection.

4.2 Total net weight of the material (including back-ordered material) shall be as specified on the purchase order.

4.3 Receiving inspection shall select one of the following tests to be run on each lot or batch.

- a. Silica content per para 5.2
- b. Fiber diameter per para 5.1

4.4 Kaowool Bulk A which meets the requirements of this specification shall be so identified and released for production use.

5. Test Procedures

5.1 Fiber Diameter: A photomicrograph shall be taken at 1000X magnification to show a minimum of 5 separate fibers. A total of at least ten diameter measurements shall be made on a minimum of 5 fibers. Measurements shall be evenly spaced on all in-focus fibers.

Fiber diameter in microns = Fiber diameter in inches X25400

5.2 Silica Content: Silica content shall be determined, using the method described in "Elementary Quantitative Analysis", H. H. Willard, H. H. Willard and N. H. Furman, third edition, page 406.

The average of duplicate samples shall be reported.

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