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"Mimetic" molecular composites of Kevlar® aramid/poly(*p*-phenyleneterephthalamide)*

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"Mimetic" molecular composites can be viewed as hybrids of conventional and "molecular" composites, and are prepared from a matrix and reinforcing fiber consisting of a single polymer composition. The aim of the work was to obtain a good chemical, physical and thermal property match at the interface for an overall excellent balance of composite properties. Kevlar® aramid 49/poly(*p*-phenyleneterphthalamide, an all-PPD-T† composite, was used as a model system in the work, and, in theory, should be ideal for testing the merit of the "mimetic" molecular composite concept. The key to the successful preparation of all-PPD-T infusible composites was the acid catalyzed thermal transformation of a fusible precursor, poly(N,N′-di-*sec*-butyl-*p*-phenyleneterephthalamide), into PPD-T. The composites were prepared by embedding Kevlar® aramid 49 fibers in poly(N,N′-di-*sec*-butyl-*p*-phenyleneterephthalamide) resin, which, on heating in the presence of benzene sulfonic acid catalyst, dealkylated to a PPD-T matrix. In this way, Kevlar® aramid 49/PPD-T(8/92 to 40/60 v/o) composites with densities in the range of 0.2 to 1.2 $\mathrm{g\,cm^{-3}}$ (versus $\sim$1.4 $\mathrm{g\,cm^{-3}}$ for a fully consolidated PPD-T composite) have been prepared and their thermal and mechanical properties characterized. Some of the foamed composites prepared in this work bear a remarkable resemblance to wood, a natural fiber reinforced foam composite, but with the advantages of flame and rot resistance. *© 1999 Kluwer Academic Publishers*

1. Introduction

There now exists a body of work [1] on the preparation of high performance composites based on the concept of molecular composite first reported on by Helmininak *et al.* [2]. In this approach, the goal has generally been to disperse the reinforcing and matrix elements on a molecular level to obtain efficient adhesion and the highest possible aspect ratio for the rigid component. However, in most cases, the dispersion of these components takes place on a microscopic level due to phase separation of the more rigid component [2–9]. On the other hand, in the early work of Helminiak *et al.* [2] two almost ideal single polymer systems were investigated and consisted of *para*-configured poly (*p*-phenylenebenzimidazole) and poly(*p*-phenylene-*cis*-benzobisoxazole). When precipitated from dilute solutions, these polymers unexpectedly gave good quality films rather than discrete particles. These materials were called neat composites or non-reinforced composites since their preparation did not rely on the use of separate matrix and fiber reinforcing elements. This work was followed by utilizing a blend of the rigid rod polymer, poly(*p*-phenylene-*trans*-benzobisthiazole) (PBT) to reinforce a flexible coil material, poly(2-5(6)benzimidazole) (ABPBI) [3]. The intent was to form a PBT/APPBI composite on the molecular level analogous to advance chopped fiber composites. Despite phase aggregation of the PBT chains to form microscopic bundles, very efficient reinforcement of the continuous ABPBI phase was achieved, and the results appeared to be a verification of the potential beneficial effects of the molecular composite concept. The current paper aims to describe a novel approach to achieving an optimum and symbiotic relationship between a matrix and fiber reinforcing elements. The approach involved the exploration of "mimetic" (meaning to mimic) molecular composites as a route to high performance structural mateials. "Mimetic" molecular composites can be viewed as hybrids of conventional and "molecular" composites where special care is taken to match the chemical, thermal, and physical properties of the reinforcing and matrix elements. The structural materials aspect means that 3-dimensional materials are emphasized rather than the 2-dimensional ones for the above molecular composites. In the work so far, Kevlar®

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*Contribution #7691.

†The original Du Pont Company code of PPD-T is used in this paper for poly (*p*-phenyleneterephthalamide) rather than PPTA, except when referring to literature work using the latter.

aramid 49/poly(*p*-phenylene-terephthalamide), an all PPD-T composite, has been used as a model system which, in theory, should be ideal for testing the merit of this concept for formation of unique structural materials. The idea for using this fiber/resin couple had its genesis in the previously reported work on high performance PPD-T foams prepared via the acid catalyzed thermal dealkylation of poly(N,N′-di-*sec*-butyl-*p*-phenyleneterephthalamide) (**1**) (see figure below) [10]. In that work, self-reinforcement of the cell walls by oriented PPD-T chains was described. It was believed that the work could be extended to the preparation of consolidated PPD-T resin using properly chosen conditions, and that Kevlar® aramid fiber could be added for a substantial boost in physical and thermal properties. It should be noted that an all-PPD-T composite has been previously reported, but the work was restricted to 2-dimensional film-like materials prepared via bonding Kevlar® aramid 49 yarns together by surface treatment with strong bases, such as in the dimsyl anion in dimethyl sulfoxide, followed by neutralization [11].

TABLE I Conditions for the preparation of the high density PPD-T foam

Time (min)	Mold temp. (°C)	Platen pressure (MPa)
0	25	0.10
30	108	0.10
45	137	0.10
105	193	0.10
120	196	0.10
195	260	7.0
245	301	7.0
285	325	70
290	331	70
320	256	0.10

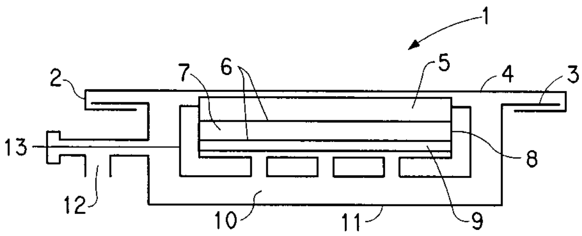


Figure 1 Schematic of vacuum bag apparatus.
Upper platen 1 (not shown);
Kapton® polyimide film (2 mil) vacuum bag cover 2;
High temperature sealant tape on lip of vacuum can 3;
Teflon® polytetrafluoroethylene coated porous glass fabric (does not cover lip of vacuum can) 4;
Mold ram (or press bar) 5;
Kapton® polyimide film (2 mil) (held to press bar with transfer tape #463) 6;
Foam or composite precursor 7;
Kapton® polyimide film 8;
Lift bar (screw driven) 9;
Bottom of mold with lift bar holder 10;
Bottom of can (in some cases contains spacers) 11;
Vacuum port with thermocouple attached to short side of can 12; and Thermocouple 13.

2. Experimental

2.1. Preparation of a high density PPD-T foam bar

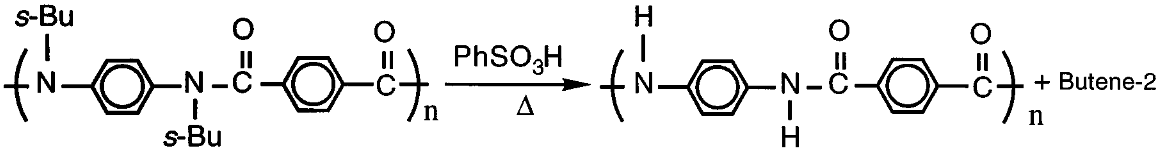
To a 250 ml round bottom flash equipped with a glass shaft and Teflon® stirrer, nitrogen inlet and Claisen head connected to condenser and graduated cylinder were added 100 ml of *o*-dichlorobenzene, 0.54 g benzenesulfonic acid and 50 g of N,N′-di-*s*-BuPPD-T with η_{inh} of 0.48 dl g^{-1} (0.5 wt % at 30 °C in H_2SO_4). The flask was inserted into a 260 °C oil bath where a clear solution was obtained within a short time before distillation began. About 80 ml of *o*-dichlorobenzene was removed, during which the mixture began to foam. The mixture was allowed to cool to room temperature (RT) and 56 g of product was collected. An aliquot of this material was micromilled in a small lab micromill. Four grams of the resulting finely ground product was spread evenly onto the surface of the bar mold (see Fig. 1) which in turn was placed into a vacuum bag apparatus. The vacuum bag apparatus set-up is also shown in Fig. 1.

The assembly was placed in a 20.6 cm × 30.5 cm Pasadena press and after purging with argon and evacuating several times, was heated under pump vacuum under conditions shown in Table I. Upon allowing to cool to RT, a bar with dimensions of 0.12 cm thick × 1.27 cm wide × 15.2 cm long, density $= 0.97$ g cm^{-3} was collected. The sample was found to be insoluble (swollen gel formed) in H_2SO_4 for measurement of the η_{inh}. The elemental and infrared analyses of the product corresponded to that of poly(*p*-phenyleneterephthalamide) [10]. The latter showed virtually no absorption at 3.38 μm, 3.40 μm and 3.47 μm for residual *s*-butyl groups. The limiting oxygen index was 0.30, which is the same as for Kevlar® aramid.

2.2. Preparation of high density Kevlar®/PPD-T composite

Step A - Impregnation of Kevlar® 49 yarn with N,N′-Di-*s*-BuPPD-T

To a 250 ml round bottom flask equipped with a glass shaft and Teflon® stirrer blade, nitrogen inlet and Claisen head connected to a condenser and graduated



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"FOAM"

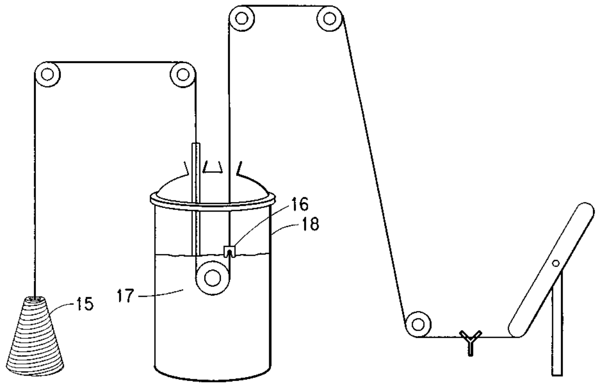


Figure 2 Process schematic of apparatus for coating of Kevlar® Aramid 49 yarn with PPD-T foam precursor poly(N,N′-di-*sec*-*p*-phenyleneneterrephthalamide).

cylinder were added 100 ml *o*-dichlorobenzene, 0.54 g of benzenesulfonic acid and 50 g of N,N′-di-*s*-BuPPD-T with an inherent viscosity of 0.49 dl g^{-1}. The flask was inserted into a 255 °C oil bath where a clear solution was obtained in a short time and before distillation of the *o*-dichlorobenzene began. About 70 ml of the *o*-dichlorobenzene was removed by distillation. The stirrer was removed from the system and, utilizing the apparatus shown in Fig. 2, the yarn 15 was coated with the plasticized melt. The yarn 15 was first threaded through a spinneret-type die 16 which was attached to a stainless steel wire threaded with 195 denier Kevlar® 49 which holds the spinneret in place. The die 16 was lowered into the melt 17 taking care to keep the top above the level of the melt. The die removes excess coating. The angle of the yarn approaching the die was kept at about 90 degrees using a stainless steel wire guide in the form of a pigtail (not shown). The yarn was taken through the die 16 at about 20 m min^{-1}. The melt solidified within seconds after exiting the flask 18 for there was little sticking. The coated yarns had a denier of about 1000 versus 195 for the Kevlar® 49 yarn.

Step B—Formation of composite using vacuum bag procedure

Coated strands (577–15.2 cm long) with a total weight of 9.74 g (wt % add-on = 80) from above were arranged in a parallel array in the mold (Fig. 1) and the pressure bar inserted and pushed down snug by hand. The mold was then placed in the vacuum bag apparatus (see Fig. 1) and heated in a Pasadena press according to the conditions shown in Table II. Upon cooling to about 100 °C, the assembly was removed from the press and the mold removed and opened and the composite bar forced out with the lift bar. The composite bar weighed 5.40 g and had dimensions of 0.24 cm (thickness) $\times$ 1.27 cm (width) $\times$ 15.3 cm (lengh), and a calculated density of $\sim$1.16 g cm^{-3}.

TABLE II Conditions for the preparation of the high Density Kevlar®/PPD-T composite

Time (min)	Temp. (°C)	Mold vac. (mm Hg)	Platen pressure (MPa)
0	22	<8	0.10
30	71	<8	0.10
90	172	<8	0.10
105	192	<8	0.10
110	210	<8	0.10
120	232	<8	0.10
135	244	<8	0.10
145	244	<8	0.10
155	247	<8	2.2
240	284	<8	2.2
260	280	<8	2.2
275	288	<8	2.2
285	293	<8	2.2
305	299	<8	2.2
315	302	<8	2.2
360	295	<8	2.2
375	304	<8	2.2
395	306	<8	2.2
405	283	<8	2.2
425	211	1 atm	0.10

TABLE III Conditions for the preparation of the low density Kevlar®/PPD-T composite

Time (min)	Temp. (°C)	Mold vac (mm Hg)	Platen pressure (kPa)
0	31	100	100
20	145	100	100
25	175	100	100
27	200	100	100
30	221	100	100
32	245	100	100
35	263	100	100
40	290	100	100
41	295	50	100
42	300	50	100
49	314	1	100
50	315	1	100
52	318	1	100
59	323	1	100
62	325	1	100
65	327	1	100
69	329	1	100
72	330	1	100
75	330	1	100
85	320	1 atm	100

2.3. Preparation of low density or foamed Kevlar®/PPD-T composite

Step A—The yarn was impregnated in the same way as above and had a denier of 1007.

Step B—Coated strands (288–15.2 cm long) with a total weight of 4.68 g. (Note that in this experiment only half the number of strands were used as in the experiment above for the high density composite.) After charging into the apparatus described above, the system was heated according to conditions shown in Table III. The foamed composite bar weighed 3.4 g and had dimensions of 0.81 cm (thickness) $\times$ 1.22 cm (width) $\times$ 15.3 cm (length), with a calculated density of $\sim$0.23 g cm^{-3}.

3. Results and discussion

3.1. Preparation of "mimetic" molecular composites

A series of all-PPD-T "mimetic" molecular composites were prepared by embedding Kevlar® aramid

TABLE IV Mechanical properties[a] of unidirectional Kevlar®//PPD-T "mimetic" molecular composites versus Kevlar®//epoxy, selected molecular composites and other representative materials

Entry	Material	Composite density ($g\,cm^{-3}$)	Kevlar® (vol %)	PPD-T (vol %)	Compressive strength (MPa)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Ref.
1	Kevlar® 49//PPD-T	1.16	29	51	—	—	—	300 600[b]	27 54[b]	This work
2	Kevlar® 49//PPD-T	1.08	40	35	—	—	—	59 122[b]	33 68[b]	This work
3	Kevlar® 49//PPD-T	0.89	27	34	—	260 580[b]	15	—	— 34[b]	This work
4	Kevlar® 49//PPD-T	0.71	12	40	76 380[b]	—	—	—	—	This work
5	Kevlar® 49//PPD-T	0.63	14	29	73 310[b]	—	—	140 600[b]	12 51[b]	This work
6	Kevlar® 49//PPD-T	0.23	9	7	15 100[b]	—	—	—	—	This work
7	PPD-T	0.14	—	10	0.90	—	—	—	—	This work
8	PPD-T	0.17	—	12	2.8	—	—	—	—	This work
9	PPD-T	0.44	—	31	—	—	—	— 28	1.1	This work
10	PPD-T	0.97	—	70	—	—	—	54	3.1	This work
11	All-Kevlar® 49	—	—	ca 100	—	1455	89	—	—	[11]
12	Kevlar® 49// Epoxy 3501-6 (60/40 v/o)[c]	1.38	60	—	280	1450	75	620	62–76	This work
13	Nome® Honeycomb	0.14	—	—	11	—	—	—	—	[14]
14	PBT/ABPBI (30/70)[d]	—	—	—	—	925 (as cast) 1283 (drawn)	33.3 (as cast) 93.8 (drawn)	—	—	[3] [3]
15	PPTA/PA6 (5/95)[e]	—	—	—	—	54	1.8	—	—	[8]
16	DBA/PA6 (50/50)[f]	—	—	—	—	51	3.3	—	—	[4]
17	Balsa	0.17	—	—	12	—	—	16	3.8	[15]

[a] In general, results are for single specimens and are measured parallel to fiber axis with the exception of flexural properties which are normal to fiber axis. Method: Flexural - ASTM D790-84a; Tensile - ASTM D3039-76; Compressive - ASTM D695-84.

[b] Normalized to 60 v/o for comparison with Kevlar® 49//epoxy (60/40 v/o).

[c] Data from DuPont Composites Division.

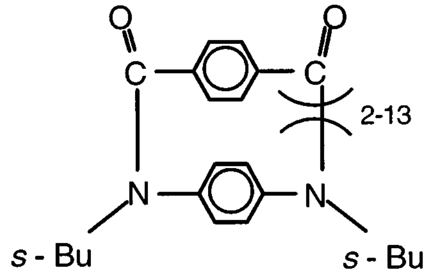
[d] Poly(phenylene-*trans*-benzobisthiazole)/poly-2,5(6)benzimidazole.

[e] Poly(*p*-phenyleneterephtalamide)/Nylon 6.

[f] Poly(4.4′diaminobenzanilide-2,6-napthalamide)/nylon 6.

49 fibers in poly(N,N′-di-*sec*-butyl-*p*-phenyleneterephthalamide) resin, which on heating in the presence of benzene sulfonic acid catalyst, dealkylated to a PPD-T matrix. In this way, foamed and nearly consolidated Kevlar® aramid 49/PPD-T (8/92 to 40/60 v/o) composites have been prepared with densities of 0.23 to 1.2 $g\,cm^{-3}$ (versus ~1.4 $g\,cm^{-3}$ projected for a fully consolidated composite) (see Table IV, entries 1–6). At this time, the process involves the following steps:

1. Preparation of N,N′-di-*sec*-butyl-PPD-T from terephthaloyl chloride and N,N′-di-*sec*-butyl-*p*-phenylene diamine (a commercial antioxidant) via high temperature solution polymerization in *o*-dichlorobenzene [10];
2. Dissolution of N,N′-di-*sec*-butyl-PPD-T in *o*-dichlorobenzene to form a 50% solution then add about 0.5% benzenesulfonic acid catalyst. Alternatively, the polymerization mixture can be used directly;
3. Removal of ≥75% *o*-dichlorobenzene by distillation giving a plasticized melt of N,N′-di-*sec*-butyl-PPD-T at about 200 °C. It is likely that cyclic oligomers (**2**) aid plasticization of the polymer in the melt [12];
4. Coating of Kevlar® aramid 49 yarn by running strands through the melt and up through a die to control the amount of N,N′-di-*sec*-butyl-PPD-T resin added on;



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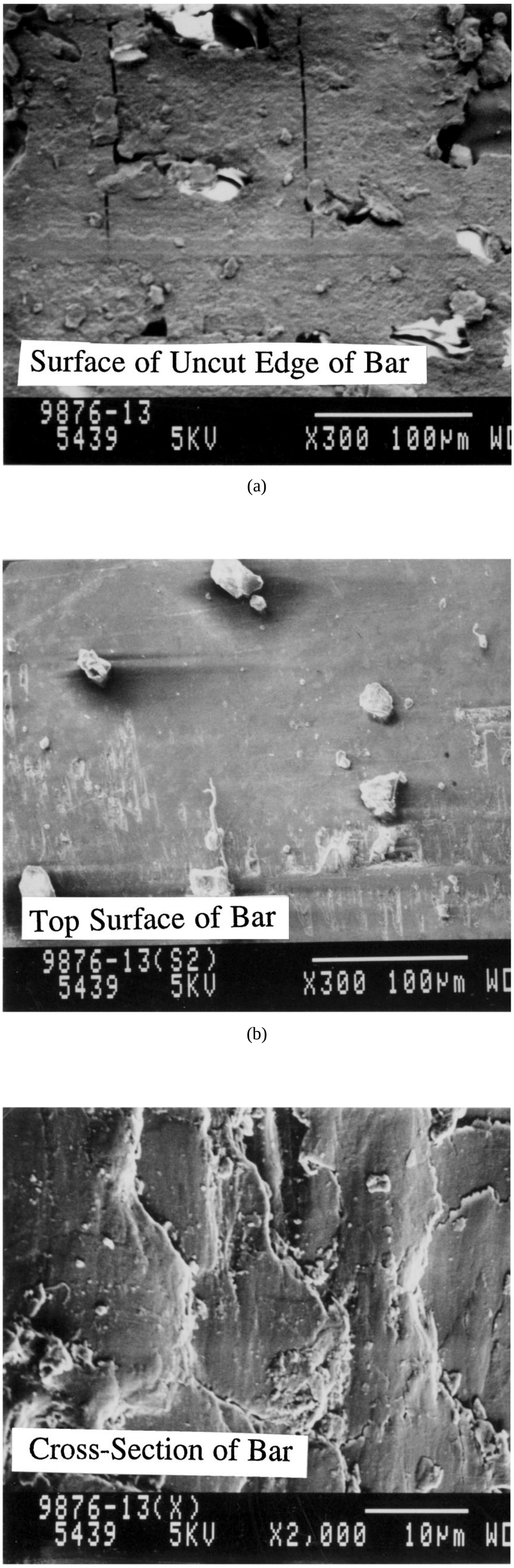
5. Placing a parallel array of coated yarns into a bar mold; and
6. Heating (about 3 h) under nitrogen using a vacuum bag procedure at programmed temperatures from room temperature up to as high as 340 °C then cool under nitrogen. Specimen thickness and compaction are controlled via degree of foaming, pressure and shims.

3.2. Physical properties of "mimetic" molecular composites

At first, the foamy nature of the initial composites was viewed as a deficiency but this view changed sharply when it was found that these reinforced foams exhibited promising properties, especially in compression and flex modes. To illustrate the potential of these reinforced foams, compressive and flexural properties along with tensile properties are shown in Table IV versus properties for unreinforced PPD-T foams, a fully consolidated Kevlar® 49/epoxy composite, selected molecular composites, a Nomex® honeycomb, and balsa wood. Note the high compressive strength for the foamed composites at only 12 v/o and 14 v/o fiber loading (see entries 4 and 5, respectively, versus Kevlar®/epoxy (60/40 v/o) (entry 12) which is indicative of the good bonding considering that the matrix is foamed. When normalized to 60 v/o fiber, these two composites exhibited excellent compressive strength versus Kevlar®/epoxy (60/40 v/o). The assertion of good matrix/fiber bonding is also apparent in the magnitude of the flexural properties of foamed composite with 14 v/o fiber (entry 5) and also in those of the fairly well consolidated (density 1.16 g cm^{-3}) composite (entry 1) with 29 v/o fiber. The nearly consolidated character of the latter material was confirmed by scanning electron microscopy (SEM). Fig. 3a to c shows SEM micrographs for the edge surface, top surface, and cross-section, respectively, for a bar of this material. Again, when normalized to 60 v/o fiber for comparison with Kevlar®/epoxy (60/40 v/o), the flexural properties were quite good. Finally, it should also be noted that a multi-fold increase in compressive and flexural properties was found in going from the unreinforced foams to the reinforced ones containing as little as 9 v/o fiber (compare entries 7, 8, and 9 with 5 and 6).

In the case of the low density reinforced foam (entry 6), the compressive strength appeared to compare very favorably with that of Nomex® honeycomb: a compressive strength of 15 kPa was found at a 9 v/o fiber loading and a density of 0.23 g cm^{-3} versus 11 kPa

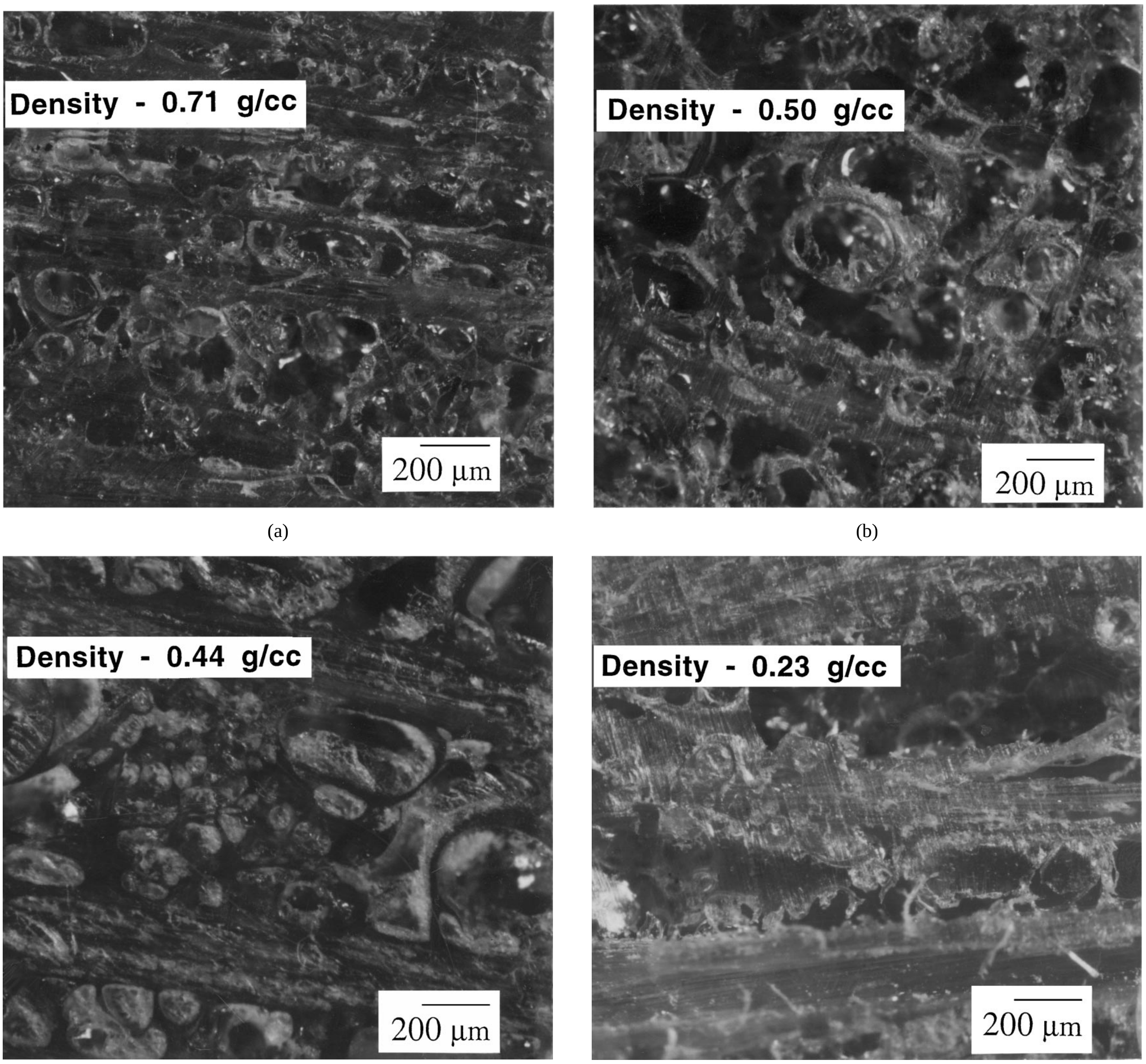


(a)

(b)

(c)

Figure 3 Scanning electron micrographs of Kevlar® Aramid 49/PPD-T composite bar.



(a) (b) (c) (d)

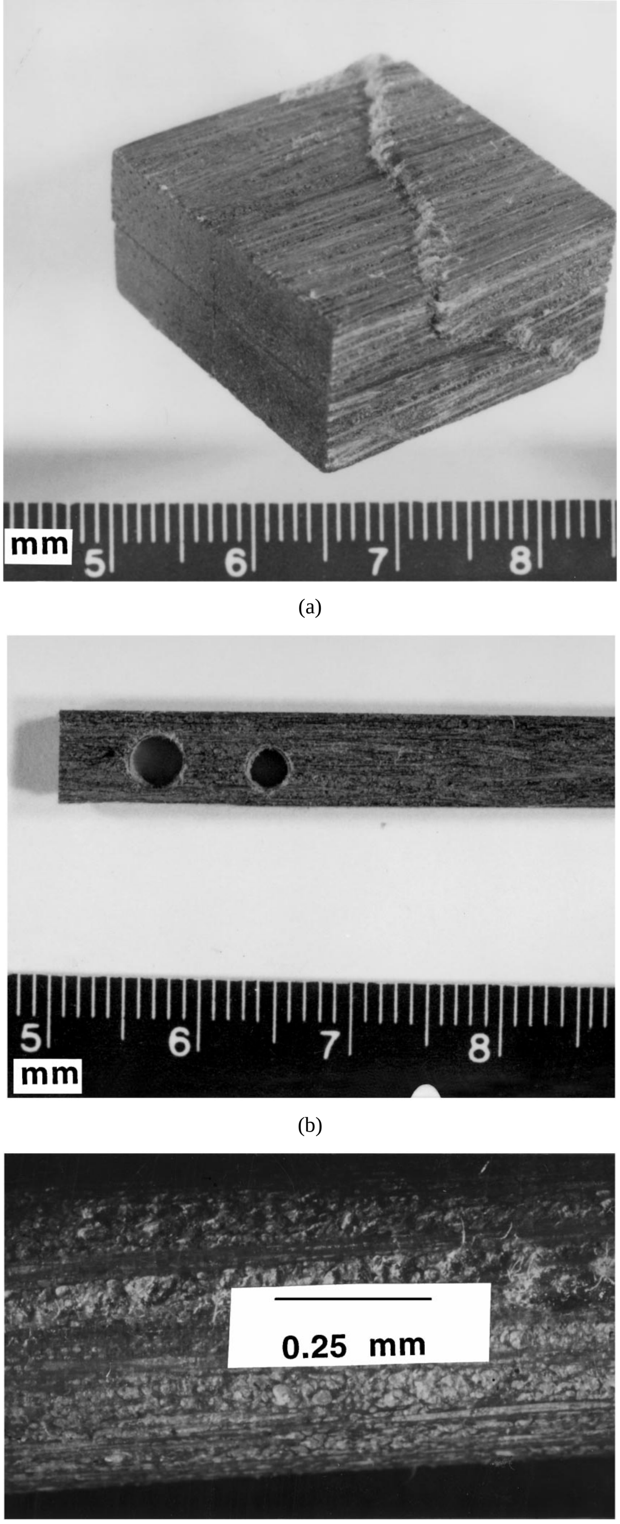
Figure 4 Photomicrographs of Kevlar® Aramid 49 fiber reinforced PPD-T foamed composites.

for the 0.14 $\mathrm{g\,cm^{-3}}$ honeycomb (entry 13). Specimens with higher quality (cell uniformity) and lower density will have to be prepared to obtain a better comparison with Nomex® honeycomb. Fig. 4 shows photomicrographs of the foamed composites with densities from 0.71 down to 0.23 $\mathrm{g\,cm^{-3}}$ and clearly shows that the uniformity decreases as the density decreases. Once uniformity is improved with an optimum arrangement of the reinforcing fibers for improved properties, these low density reinforced foams could find applications in structural core markets now dominated by honeycomb structures. Further, higher quality (e.g. higher MW) precursor polymer is needed and can possibly be prepared via N-alkylation of PPD-T using chemistry involving alkylation of PPD-T dianion in dimethylsulfoxide [13]. Results from these experiments could also lead to polymers which convert more easily to PPD-T in order to avoid thermal decomposition of both the matrix and fiber. Reinforced foams have three potential advantages over honeycombs in that they can: 1) be easily machined to desired shapes (see discussion below); 2) sometimes be foamed in place avoiding machining altogether; and 3) form their own skin sometimes eliminating the need for laminating a skin onto the surface and hence circumvent potential delamination problems which plague honeycomb sandwich structures.

3.3. "Mimetic" molecular composites versus molecular composites

Tensile strength and modulus values are listed in Table IV for three representative molecular composites: Poly(phenylene-*trans*-benzobisthiazole)/poly-2,5(6)benzimidazole (30/70) (PBT/ABPBI) (entry 14), Poly(*p*-phenyleneterephtalamide)/Nylon 6 (5/95) (PPTA/PA6) (entry 15), and Poly(4.4′ diaminobenzanilide-2,6-napthalamide)/nylon 6 (50/50) (DBA/PA6) (entry 16). Of these, the tensile properties of PBT/-ABPBI, with a loading of 30 vol % PBI in both the undrawn and drawn state (unidirectional), are superior to a comparably loaded (27 v/o) Kevlar® aramid 49 fiber “mimetic” molecular composite with a density of 0.89 $\mathrm{g\,cm^{-3}}$. On the other hand, the “mimetic” composite was found to be much superior to an undrawn molecular composite based on the aramid DBA at a much higher loading (50 v/o) in nylon 6. This result might be expected on the basis of the unidirectionality of the fiber reinforcement for the “mimetic” composite. The tensile properties of the “mimetic” composite are also far superior to those of PPTA/PA6, but unfortunately the loading of the PPTA is much too low (5 v/o) in the latter for a meaningful comparison.

It is felt that there is great potential for preparing 3-dimensional “mimetic” all-PPD-T composites with outstanding tensile properties, especially if high volume loadings of the fiber can be successfully utilized. Results on previously reported 2-dimensional film-like all-PPD-T composites support this contention: note the very high tensile properties of a composite prepared by bonding of Kevlar® aramid 49 filament surfaces together using dimsyl anions in DMSO (Table IV, entry 11) [11]. Presumably, a thin layer of an isotropic or partially anisotropic matrix of anions of PPD-T in DMSO was formed in this work which bonded the bundles of fibers together.



(a)

(b)

(c)

Figure 5 Photographs of Kevlar® Aramid 49 reinforced PPD-T foamed composites; (a) compression tested specimen; (b) drilled specimen; and (c) turned specimen.

3.4. “mimetic” molecular composites versus other cellular materials

Fig. 5 shows photographs of three specimens of Kevlar® aramid fiber reinforced PPD-T foams. These materials exhibit an astonishing resemblance to wood, a natural foamed composite, in their appearance, their machinability, and in their failure mode in compression (see Fig. 5a versus Fig. 6 for a depiction of compression failure in a sample of wood). The specimens were cut on a band saw and the sample with holes (Fig. 5b) was drilled with a mechanical wood drill. In the case of the sample shown in Fig. 5c, turning was carried out on a lathe using a hand bastard file with subsequent surface smoothing using a mill smooth file, and 240A, 400A, and 600A Type Tufback Durite sand paper, respectively. The resemblance to wood is believed to be due to the way light is reflected from the surfaces of the fiber reinforced foam composites. The appearance can be further modified by changing the configuration of the fiber reinforcement to a multi-directional orientation such as in a fabric or felt. Fig. 7 shows the specific compressive strength (parallel to the fiber direction) of three of the foamed composites versus that of a number of woods, Kevlar® aramid reinforced epoxy, Nomex® aramid honeycomb, and a glass/phenolic/polyimide syntactic foam. First, the non-unifomities and low fiber content of the two very low density foamed composites (bars C and D) place them in a relatively poor position opposite most of the materials listed. However, as the density was increased to 630 and 710 $\mathrm{kg\,m^{-3}}$ (bars H and J) giving much more uniform materials, and with increased fiber content to 14 and 12 v/o, respectively, the “mimetic” molecular composites exhibit outstanding properties and are superior to some of the highest performance woods in existence, such as yellow birch, greenheart, lignum vitae, and balsa, all with much higher fiber contents. These natural foamed composites [15] are still being used in many structural applications: substitutes for metal bearing in heavy machinery, pulleys, and bed and chair castors, in the case of lignum vitae; ship and dock building, bridges, and trestles, in the case of greenheart; and floats, rafts, boats, and sound absorbers, in the case of balsa.

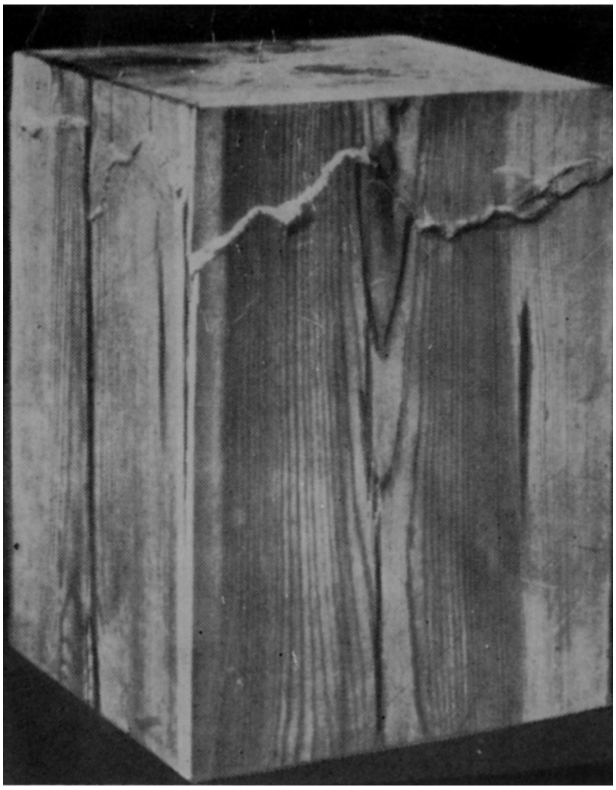


Figure 6 Photomicrograph* of clear wood specimen with density of 0.51 g cm^{-3} taken after crushing failure.

*Reproduced from: F. F. P. Kollmann and W. A. Cote, Jr. in "Principles of Wood Science and Technology I Solid Wood" (Springer-Verlag, New York, 1968) p. 353.

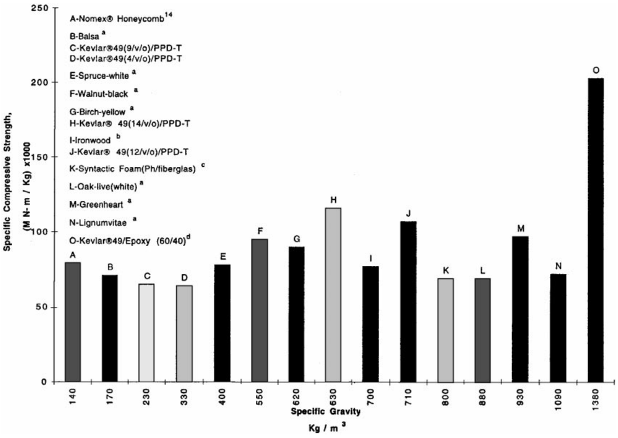


Figure 7 Specific compressive strength of Kevlar® Aramid 49 reinforced PPD-T foams versus woods and other selected high performance materials.

[a] *Wood Handbook: Wood as an engineering material*, Forest Products Laboratory, U.S. Forest Service, U.S. Dept. of Agriculture, Agriculture Handbook No. 72, Revised 1974.

[b] Handbook of Material Science, Vol. IV. R. Summitt and A. Silker, Eds., CRC Press, 1980.

[c] Material Engineering, pp. 51–54, Sept., 1987.

[d] Data from Composites Division, DuPont Company.

Furthermore, the "mimetic" composites discribed in this work are both flame and rot resistant. Finally, the specific compressive strengths of these foamed composites are superior to the high performance syntactic foam (bar K) used in marine and deep sea applications.

TABLE V Flexural properties[a] versus temperature for Kevlar® 49//PPD-T composite bar with density of 1.08 g cm^{-3}

Temperature (°C)	Flexural strength (MPa)	Flexural modulus (GPa)	Maximum strain (%)
23	59	33	0.17
150	74	29	0.23
200	69	23	0.27
300	72	23	0.30

[a] ASTM Method D790-84a; span/thickness = 16.

3.5. Thermal properties of "mimetic" molecular composites

The "Mimetic" molecular composites prepared in this work exhibit thermal properties similar to those of Kevlar® aramid when examined by differential scanning calorimetry (DSC) and thermogramimetric analysis (TGA) in nitrogen, and by measurement of mechanical properties at elevated temperatures. The composites exhibit a strong decomposition endotherm at ∼550 °C corresponding to the temperature for TGA decomposition. From a mechanical property point of view, the composites exhibited outstanding retention of properties at elevated temperature judging by the retention of flexural strength and modulus retention out to 300 °C (Table V). As a matter of fact, there seems to be a surprising increase of flexural strength with temperature whereas the modulus follows the expected downward trend found for Kevlar® aramid fiber [16]. In any case, the data confirms the expected high temperature performance of the PPD-T matrix when paired with Kevlar® aramid fiber in a composite material.

4. Conclusions

Three-dimensional foamed and consolidated "Mimetic" molecular composites consisting of a matrix and reinforcing fiber of the same composition, poly(*p*-phenyleneterphthalamide), can be prepared. The key to the successful preparation of these all-PPD-T high temperature composites was the acid catalyzed thermal transformation of a poly(N,N′-di-*sec*-butyl-*p*-phenyleneterephthalamide) precursor matrix into PPD-T. The aim of the work was to achieve a good chemical, physical and thermal property match at the interface for an overall excellent balance of composite properties. The all-PPD-T nature of the materials should assure a good match in all three areas. Although the results confirmed the expected high temperature performance of the PPD-T matrix when paired with Kevlar® aramid in a composite material, it was not established that the resulting composites exhibit truly unique mechanical properties versus composites having two or more polymer systems. A test of the ultimate uniqueness of a single polymer composite of the type (rigid rod) described in this work will have to wait for optimization of composite properties, especially of the consolidated type, via improved processes. In any case, it would appear that the wood-like foamed composites prepared in this work already exhibit novel properties.

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