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1
2
3 LIGHTWEIGHT HIGH DAMPING POROUS METAL/PHTHALONITRILE COMPOSITES
4

5 **Background of the Invention**

6 **1. Field of the Invention**

7 The present invention relates generally to lightweight
8 composites and more specifically to lightweight composites with
9 good acoustic damping properties.
10

11 **2. Description of the Background Art**

12 In many cases, such as in factories, motor vehicles, ships,
13 and submarines, it is desirable to absorb as much noise as
14 possible. In factories, absorbance of machinery noises can
15 minimize noise pollution caused by industrial sounds. In motor
16 vehicles, absorbance of engine noises and noises from road
17 vibration enhances driver and rider comfort. In submarines and
18 ships, the absorbance of machinery sounds helps prevent detection
19 and identification by unfriendly forces. Additionally, in regions
20 where earthquake are common, the structural components of
21 buildings, bridges, and similar artifacts must not only be strong,
22 but should be able to dampen vibrations.

23 Past noise reduction efforts have previously taken one of two
24 approaches. The use of soft coupling components (e.g., bushings,
25 pads) to isolate machinery, and the incorporation of structural

1 acoustic damping materials.

2 Both of these prior art approaches have had drawbacks. Soft
3 coupling components add weight to a device, may require
4 maintenance, and may not be consistent with the required design and
5 performance features. Currently available acoustic damping
6 materials do not exhibit adequate acoustic behavior over broad
7 ranges of temperature, lack the required strain amplitude and
8 frequency, or do not have the desired strength and environmental
9 resistance.

10 Significant advances have been made to increase the strength
11 and stiffness of lightweight materials. Examples of these
12 developments include the superior density-normalized strength and
13 stiffness of Al-Li, hard dispersion strengthened aluminum and
14 titanium, aluminides, and whisker or fiber reinforced aluminum and
15 magnesium. Although those materials have excellent structural
16 characteristics, the demand continues for high strength,
17 lightweight structural materials that also vastly improve damping
18 capability.

19 United States Patent No. 4,759,000, the entirety of which is
20 incorporated herein by reference for all purposes, to Ronald P.
21 Reitz describes acoustically transparent windows made of an
22 aluminum/nickel foam impregnated with an acoustically non-absorbent
23 rubber such as BE silicone rubber RTV-11. Nothing in that patent
24 teaches or suggests that a useful material may be obtained by
25 impregnating a metal foam with an acoustically absorptive polymer.

1 alloy foam/phthalonitrile composite, heat treated under the various
2 condition described in the accompanying Example 3.

3
4 Fig. 2, Fig. 3 and Fig. 4 show the results of damping
5 measurements for a copper foam/phthalonitrile composite, over a
6 frequency range of 0.1 to 10 Hz.

7
8 Fig. 5, Fig. 6, and Fig. 7 show the damping behavior of a
9 titanium foam/phthalonitrile composite under different heat
10 treatment conditions as described in Example 5.

11
12 Fig. 8 and Fig. 9 show the damping behavior of a zinc
13 foam/phthalonitrile composite under different heat treatment
14 conditions as described in Example 5

15
16 Fig. 10 is a graph showing the $\text{Tan}\delta$ over a frequency range of
17 0.1 to 10 Hz for various polymers and metal foams.

18
19 **Description of the Preferred Embodiments**

20
21 The metal foam of the present invention may be any porous
22 metal workpiece, particularly a metal foam, regardless of shape or
23 percent density, having an open cell structure that permits
24 impregnation with an uncured polymer. Particularly useful metals
25 include aluminum, titanium, nickel, copper, iron, zinc, lead,

1 silver, gold, platinum, tantalum, and alloys (including steel)
2 based on these metals. Other metals may also be used. Aluminum
3 and titanium and alloys thereof are particularly useful because of
4 their low density.

5 Metal foams may be produced by a variety of known methods.
6 For example, a molten metal may be placed under high pressure so
7 that it dissolves a non-reactive gas. When the pressure is
8 released and the metal is allowed to cool, the dissolved gas
9 escapes and leaves open-celled pores in the metal body. In other
10 processes, foaming agents are added to molten metal. Another
11 process mixes monomers with metal particles and heats the mixture
12 to induce foaming and solidification of the resin. As used herein,
13 the term "resin" encompasses prepolymers, monomers, and mixtures
14 thereof. A "cured resin" is the cured polymer. With further
15 heating, the metal particles consolidate and the polymer
16 hydrolyzes. United States Patent No. 4,569,821, the entirety of
17 which is incorporated herein by reference for all purposes,
18 improves upon that process by substituting a stabilized hydrogel
19 for the monomers, allowing more complete pyrolysis of the organic
20 components during formation of the metal foam.

21 In a foam, pore size is defined as the number of pores per
22 linear unit length. Because foams have only thin ligaments between
23 the pores, the void diameter of a pore is approximately the
24 reciprocal of the pore size of the foam. Decreasing the void
25 diameter increases the contact surface area between the metal foam

1 and the polymer. Also, as the percent foam density (*Foam Density*
2 = *Density of a One Unit Volume of Foam/Density of One Unit Volume*
3 of Metal x 100) of the metallic foam decreases, the final product
4 increasingly exhibits the structural characteristics of the polymer
5 material. Thus, as the percent foam density of the metallic foam
6 decreases, the stiffness of the composite decreases. Even with
7 extremely low percent foam densities, however, the stiffness of the
8 composite is superior to that of either of the individual
9 components. Percent foam density and pore size also determine the
10 number of polymer/metal interfaces that an acoustic vibration must
11 traverse. As explained below, the polymer/metal interfaces
12 contribute mainly to the sound damping capabilities of the
13 composites of the present invention. A typical useful pore size is
14 5-100 pores/inch. More often, a pore size of about 10-50 pores/inch
15 is used, and most often a pore size of about 10-40 pores/inch is
16 used. Typically, the percent foam density is about 5-40. More
17 often, the percent foam density is about 8-10.

18 Typically, to improve the predictability of the structural and
19 acoustic properties of the composite products of the present
20 invention, the pores (also referred to in the present specification
21 and claims as "cells") within the metal foam have a locally uniform
22 size and distribution. Throughout the present specification and
23 claims, a foam has a locally uniform size and distribution of pores
24 if most of the pores of the foam are surrounded by evenly
25 distributed pores having approximately the same void diameter as

1 the surrounded pore. Local non-uniformity in the size or
2 distribution of the pores within the metal foam decreases the
3 predictability of the characteristics for the resulting composite.
4 If desired, the metal foam may be divided into regions of different
5 pore size, or may have a gradation of pores sizes in any direction
6 along the metal foam, while maintaining locally uniform pore size,
7 without harming the predictability of performance.

8 The metal foam may be impregnated by any available method.
9 Typically, the metal foam is impregnated by contacting it with a
10 phthalonitrile resin component. The phthalonitrile resin component
11 a neat resin or a neat blend of resins, or may include any
12 catalysts, curing agents, or additives desired. The phthalonitrile
13 resin component may be a powder (of sufficiently small particle
14 size to penetrate the pores of the metal foam), a melt, a room
15 temperature liquid, or a solution, and may include mixtures of
16 several prepolymers and/or monomers (for example, other resins or
17 other phthalonitrile resins). A vacuum or positive pressure may
18 be applied to assist the penetration of the foam by the
19 phthalonitrile resin component. Solvent, if present, is removed by
20 evaporation. The phthalonitrile resin component is then cured
21 (after any needed consolidation step in the case of a powder
22 impregnant) by any method (typically heating) to provide an
23 infinite network phthalonitrile polymer that fills or partially
24 fills the open-cells of the metal foam.

25 Generally, the method of curing is not critical to the present

1 invention, so long as the metallic foam is not destroyed (for
2 example, by corrosion or melting) during curing. In some cases,
3 the metal foam matrix may serve as a curing catalyst. Therefore,
4 an additional curing agent may not be needed.

5 Any phthalonitrile resin may be used in the composite
6 according to the present invention. Some typical and useful
7 phthalonitriles are described in the following U. S. Patents:
8 4,408,035; 4,409,382; 4,410,676; 4,619,986; 5,003,039; 5,003,078;
9 5,004,804; 5,132,396; 5,159,054; 5,202,414; 5,208,318; 5,237,045;
10 5,247,060; 5,262,514; 5,292,854; 5,304,625; 5,350,828; 5,352,760;
11 and 5,464,929, the entireties of all of which are incorporated
12 herein by reference for all purposes.

13 The viscosity of the phthalonitrile resin component (i.e., the
14 impregnant) can be adjusted both thermally or by adjusting the
15 amount of any solvent used, if necessary. Preferably, the
16 impregnant viscosity should be selected to allow the metal foam to
17 be completely impregnated with the phthalonitrile resin component
18 under practical processing conditions. A high impregnant viscosity
19 may restrict the ability of the phthalonitrile resin component to
20 completely penetrate the open porous structure of the metal foam.
21 This problem may be overcome by forcing, under positive pressure,
22 the phthalonitrile resin component into the pores of the foam. For
23 any given impregnant used, an appropriate impregnant viscosity may
24 be selected empirically, without undue experimentation, given the
25 guidance provided by this specification and the accompanying

1 examples. Phthalonitrile resin component in powder form can be
2 forced into the pores of the metal foam by any method. For
3 example, the powdered phthalonitrile resin component may be poured
4 on top of the metal foam, and positive or negative pressure may be
5 applied to the powder, forcing it into the pores of the foam. At
6 the same time, the metal foam may be vibrated to aid in
7 impregnation.

8 The acoustic damping capabilities of the composite of the
9 present invention arise in part from the acoustic properties of the
10 polymerized resin component and in part from dissipation of energy
11 at the polymer/metal interface. Energy is never transferred
12 without loss at interfaces between different materials. Therefore,
13 as the number of interfaces that an acoustic vibration must
14 traverse increases, the percentage of dissipated acoustic energy
15 also increases. A metal foam/polymer composite provides numerous
16 interfaces between the polymer and the metal matrix.

17 For acoustic damping applications, the composite of the
18 present invention should provide a sufficient number of
19 polymer/metal interfaces to allow good acoustic damping. Thus,
20 particularly when formed as a sheet for acoustic damping
21 applications, the smallest dimension of the metal foam (for a
22 sheet, the thickness) is usually at least about 1.5 times the
23 average void diameter of the metal foam. In many cases, for
24 acoustic damping applications, the smallest dimension of the metal
25 foam will be three or more times greater than the average void

1 diameter of the metal foam.

2 Also, acoustic damping in these materials might be further
3 improved by the inclusion of polymer/gas and/or gas/metal
4 interfaces, which further increase the number of interfaces that an
5 acoustic vibration must traverse through the composite. These
6 polymer/gas and/or gas/metal interfaces may be formed by many
7 mechanisms, such as the use of a foamed resin component to produce
8 the polymeric component of the composite, the dissolution of the
9 neat resin or blend of resins in a solvent before impregnation, or
10 the inclusion of minute amounts of gas, or materials that form a
11 gas or a vapor during curing, within the resin component used to
12 form the polymeric component. The amount of gas or gas forming
13 materials should be sufficient to significantly enhance the
14 acoustic damping capabilities of the composite, but should not
15 provide sufficient gas to essentially destroy the structural
16 integrity of the composite and/or the polymeric component thereof.
17 The optimum amount of any gas or gas producing agent used in the
18 resin component will vary depending upon the desired use for the
19 composite and may be empirically determined without undue
20 experimentation.

21 The interaction of the metal foam and the polymer matrix also
22 contributes to the structural strength of the composite.
23 Consequently, the structural strength of the metal foam/polymer
24 composite is greater than the individual structural strengths of
25 the metal foam and the polymer.

1 Composites according to the present invention may be
2 constructed to exhibit acoustic damping across a frequency band
3 residing within a range of typically about 0.001-80 kHz. The
4 precise frequency band, as well as the bandwidth over which a
5 composite according to the present invention exhibits acoustic
6 damping, is determined by the selected polymer, metal, pore size
7 and percent foam density. The frequency range of damping may be
8 extending by stacking together metal foam/polymer composites having
9 different pore sizes, percent metal foam densities, polymers
10 (phthalonitrile or other polymers), and/or metals. Several sheets
11 may be laminated together with adhesive, or in some cases will bond
12 to each other during curing of one or more of the polymers within
13 the metal foams, to form a laminate. Pore size and percent metal
14 foam density may also be varied, without stacking, by providing a
15 metal foam having regions of different average pore size or having
16 an average pore size that is graded in one or more directions. It
17 may also be possible to vary the polymer used within a single
18 sheet. For example, a foam may be impregnated with a first resin
19 component. The resin component-impregnated foam may then be
20 subjected to pressure on, for example its upper surface, to force
21 any portion of the first resin component out in the upper portion
22 of the metal foam down into the lower portion. The resin
23 component-impregnated foam may then be solidified while under this
24 positive pressure. After partial or complete consolidation or
25 solidification of the first resin component in the lower portion of

1 the metal foam, the upper portion of the metal foam may be
2 impregnated with a second resin component.

3 The composites of the present invention are not only
4 lightweight, but also have excellent impact resistance relative to
5 the metals themselves. Thus, they could present an excellent
6 choice in the design of energy efficient cars. The superior flame
7 resistance and high temperature performance provided by the use of
8 the phthalonitrile polymer also make these composites extremely
9 well suited to use under extreme conditions. For example, the
10 composites of the present invention may be used as high temperature
11 high performance structural materials for extraterrestrial vehicles
12 such as the National Aerospace Plane (NASP), the next generation
13 space shuttle, reusable launch vehicles/boosters, high performance
14 heat engines, gas turbine engines, heat exchangers, and electronic
15 applications. Aside from enhanced performance, components
16 manufactured using composites according to the present invention
17 may alter the noise properties of machinery, aerospace vehicles,
18 domestic vehicles, military vehicles, commercial vehicles, marine
19 vehicles and maritime vehicles. Also, composites according to the
20 present invention are readily manufactured, for example, by resin
21 transfer molding (RTM), resin infusion molding, or resin injection
22 molding.

23
24 Having described the invention, the following examples are
25 given to illustrate specific applications of the invention

1 including the best mode now known to perform the invention. These
2 specific examples are not intended to limit the scope of the
3 invention described in this application.
4

5 EXAMPLES

6 Example 1: Preparation of phthalonitrile prepolymer

7 Phthalonitrile monomer, 4,4'-bis(3,4-dicyanophenoxy)biphenyl,
8 was purchased from Daychem Laboratories. 10 g of the monomer was
9 placed in an aluminum planchet and melted on a hot plate at 250°C
10 (monomer melts around 235°C). The monomer melt was degassed for
11 about 2h to eliminate trace amounts of solvent present. The
12 phthalonitrile prepolymer was synthesized by adding 0.15- 0.168 g
13 (1.5-1.68 wt%) of 1,3-bis(3-aminophenoxy)benzene, obtained from
14 National Starch Corporation, to the monomer melt. The melt was
15 stirred for 15 min. and was used for fabrication of
16 phthalonitrile/metal foam composite specimens.
17

18 Example 2: Fabrication of phthalonitrile/aluminum foam composite

19 An aluminum mold, 2"x0.6"x0.2", coated with a teflon mold
20 release agent was used for fabrication of composite specimens. Two
21 aluminum foam strips (1"x0.5"x0.185", density 6-8 % of the solid
22 material, pore size - 40 pores per inch (ppi)) separated by a
23 teflon film, were placed in the mold and heated to 250°C.
24 Approximately 2-3 g of the prepolymer melt synthesized as described
25 above in Example 1 with 1.68 wt% curing additive was poured over

1 the metal foam and degassed for about 15 min. with periodic venting
2 to ensure a good flow of the resin throughout the metal foam. The
3 mold was then heated in an air circulating oven for 9h at 280°C and
4 cooled back to room temperature over a 3h span. The composite
5 samples made with this prepolymer showed an incomplete penetration
6 of the resin into the metal foam. Therefore, subsequent composite
7 fabrications involved a slower curing prepolymer made with 1.5%
8 curing additive. The prepolymer has an initial lower viscosity.
9

10 Example 3: Fabrication of phthalonitrile/aluminum foam composite

11 An aluminum mold, 2"x0.6"x0.2", coated with a teflon mold
12 release agent was used for fabrication of composite specimens. Two
13 aluminum foam strips (1"x0.5"x0.185", density 6-8 % of the solid
14 material, pore size - 40 ppi) separated by a teflon film, were
15 placed in the mold and heated to 250°C. Approximately 2-3 g of the
16 prepolymer melt synthesized with 1.5 wt% curing additive was poured
17 over the metal foam and degassed for about 15 min. with periodic
18 venting to ensure a good flow of the resin throughout the metal
19 foam. The mold was then heated in an air circulating oven for 9h
20 at 280°C and cooled back to room temperature over a 3h span. The
21 composite samples made with this prepolymer showed a complete
22 penetration of the resin through the metal foam. The mechanical
23 and damping properties of the phthalonitrile/aluminum composite
24 samples were evaluated after heat treatment at the following
25 conditions: (A) 9h at 280°C (B) 18h at 280°C (C) 18h at 280, 4h at

1 325°C and (D) 18h at 280, 4h at 325,4h at 375°C. Conditions (C)
2 and (D) employed an inert atmosphere purge of argon.
3

4 Example 4: Fabrication of phthalonitrile/copper foam composite

5 An aluminum mold, 2"x0.6"x0.2", coated with a teflon mold
6 release agent was used for fabrication of composite specimens. Two
7 copper foam strips (1"x0.5"x0.185", density 6-8 % of the solid
8 material, pore size - 10 ppi), separated by a teflon film, were
9 placed in the mold and heated to 250°C. The prepolymer melt
10 synthesized as described above in Example 1 with 1.5 wt% curing
11 additive was poured over the metal foam and degassed with periodic
12 venting to ensure a good flow of the resin throughout the metal
13 foam. The mold was then heated in an air circulating oven for 9h
14 at 280°C and cooled back to room temperature over a 3h span. The
15 mechanical and damping properties of the phthalonitrile/copper
16 composite samples were evaluated after heat treatment at the
17 following conditions: (A) 9h at 280°C (B) 18h at 280°C (C) 18h at
18 280, 4h at 325°C and (D) 18h at 280, 4h at 325,4h at 375°C.
19 Conditions (C) and (D) employed an inert atmosphere purge of argon.
20

21 Example 5: Fabrication of phthalonitrile/titanium foam composite

22 An aluminum mold (2"x0.6"x0.2", density 6-8 % of the solid
23 material, pore size - 10 ppi) coated with a teflon mold release
24 agent was used for fabrication of composite specimens. Two
25 titanium foam strips, 1"x0.5"x0.185", separated by a teflon film,

1 were placed in the mold and heated to 250°C. The prepolymer melt
2 synthesized as described above in Example 1 was poured over the
3 metal foam and degassed for about 15 min. with periodic venting to
4 ensure a good flow of the resin throughout the metal foam. The
5 mold was then heated in an air circulating oven for 9h at 280° C
6 and cooled back to room temperature over a 3h span. The mechanical
7 and damping properties of the phthalonitrile/titanium composite
8 samples were evaluated after heat treatment at the following
9 conditions: (A) 9h at 280°C (B) 18h at 280°C (C) 18h at 280, 4h at
10 325°C and (D) 18h at 280, 4h at 325, 4h at 375°C. Conditions (C)
11 and (D) employed an inert atmosphere purge of argon.

12
13 Example 6: Fabrication of phthalonitrile/zinc foam composite

14 An aluminum (mold, 2"x0.6"x0.2", density 6-8 % of the solid
15 material, pore size - 10 ppi) coated with a teflon mold release
16 agent was used for fabrication of composite specimens. Two zinc
17 foam strips, 1"x0.5"x0.185", separated by a teflon film, were
18 placed in the mold and heated to 250°C. The prepolymer melt
19 synthesized as described above in Example 1 with 1.5% curing
20 additive was poured over the metal foam and degassed for about 15
21 min. with periodic venting to ensure a good flow of the resin
22 throughout the metal foam. The mold was then heated in an air
23 circulating oven for 9h at 280°C and cooled back to room
24 temperature over a 3h span. The mechanical and damping properties
25 of the phthalonitrile/zinc composite samples were evaluated after

1 heat treatment at the following conditions : (A) 9h at 280°C (B)
2 18h at 280°C (C) 18h at 280, 4h at 325°C and (D) 18h at 280, 4h at
3 325, 4h at 375°C. Conditions (C) and (D) employed an inert
4 atmosphere purge of argon.

5
6 Example 7. Preparation of Porous Metal/Phthalonitrile Composite
7 Samples for Damping Measurements.

8 For the purpose of demonstration, only selected foams and
9 phthalonitrile monomers have been used. Many metals or even high
10 strength alloys can be used as skeleton material to design the
11 composite processing requiring strength and damping capability.
12 Other factors such as environmental capability, temperature and
13 chemical capability in addition to cost can dictate the choice of
14 the materials to be used.

15
16 The composites produced in Examples 3-6 were used for damping
17 measurements. The samples were prepared for these measurements with
18 dimensions having 4.5 mm thickness, 10 mm width, and 32 mm length.
19 The damping capacity of the samples were measured with a dynamic
20 mechanical thermal analyzer (DMTA). A small sinusoidal mechanical
21 stress is applied to the sample and the resulting sinusoidal strain
22 transduced. Comparison of the amplitude of the signals yields the
23 complex dynamic modulus E^* . The phase lag (δ) of strain behind
24 stress is measured and the storage modulus and loss factor of the
25 material are calculated.

1 Example 8. Damping Characteristics of Aluminum Alloy
2 Foam/Phthalonitrile Composite.

3 The aluminum alloy foam/phthalonitrile composite prepared in
4 Example 3 was evaluated for its damping characteristics under 1 Hz
5 frequency. The results of the damping measurements were shown in
6 Fig. 1. The figure shows the damping behavior of the composite
7 under different heat treatment conditions as described in Example
8 3. The damping measurements are plotted against temperature. It is
9 noted that damping peak locations at a given temperature can be
10 adjusted based on heat treatment of composite. The room temperature
11 damping (flat portion of curve) is also higher than the best
12 damping material such as Vacrosil™ as shown in Fig. 10.

13

14 Example 9. Damping Characteristics of Copper Foam/Phthalonitrile
15 Composite.

16 The copper foam/phthalonitrile composite prepared in Example
17 4 was evaluated for its damping characteristics under 0.1 to 10 Hz
18 frequency. The results of the damping measurements were shown in
19 Fig. 2 through 4. The figures show the damping behavior of the
20 composite under different heat treatment conditions as described in
21 Example 4. The damping measurements are plotted against
22 temperature. It is noted that damping peak locations at a given
23 temperature can be adjusted based on heat treatment of the
24 composite. The room temperature damping (flat portion of curve) is
25 also higher than the best damping material such as Vacrosil™ as

1 shown in Fig. 10.
2

3 Example 10. Damping Characteristics of Titanium Foam/Phthalonitrile
4 Composite.

5 The titanium foam/phthalonitrile composite prepared in Example
6 5 was evaluated for its damping characteristics under 0.1 to 10 Hz
7 frequency. The results of the damping measurements were shown in
8 Figs. 5 through 7. The figures show the damping behavior of the
9 composite under different heat treatment conditions as described in
10 Example 5. The damping measurements are plotted against
11 temperature. It is noted that damping peak locations at a given
12 temperature can be adjusted based on heat treatment of the
13 composite. The room temperature damping (flat portion of curve) is
14 also higher than the best damping material such as Vacrosil™ as
15 shown in Fig. 10.
16

17 Example 11. Damping Characteristics of Zinc Foam/Phthalonitrile
18 Composite.

19 The zinc foam/phthalonitrile composite prepared in Example 6
20 was evaluated for its damping characteristics under 0.1 to 10 Hz
21 frequency. The results of the damping measurements were shown in
22 Fig. 8 and Fig. 9. The figures show the damping behavior of the
23 composite under different heat treatment conditions as described in
24 Example 5. The damping measurements are plotted against
25 temperature. It is noted that damping peak locations at a given

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PATENT APPLICATION

1 temperature can be adjusted based on heat treatment of the
2 composite. The room temperature damping (flat portion of curve) is
3 also higher than the best damping material such as Vacrosil™ as
4 shown in Figure 10.

5
6 Additional information concerning the present invention may be
7 found in the copending United States Patent Application of Imam,
8 Rath and Keller, entitled POROUS METAL/ORGANIC POLYMERIC
9 COMPOSITES, filed on even date herewith, the entirety of which is
10 incorporated herein by reference.

11
12 Obviously, many modifications and variations of the present
13 invention are possible in light of the above teachings. It is
14 therefore to be understood that

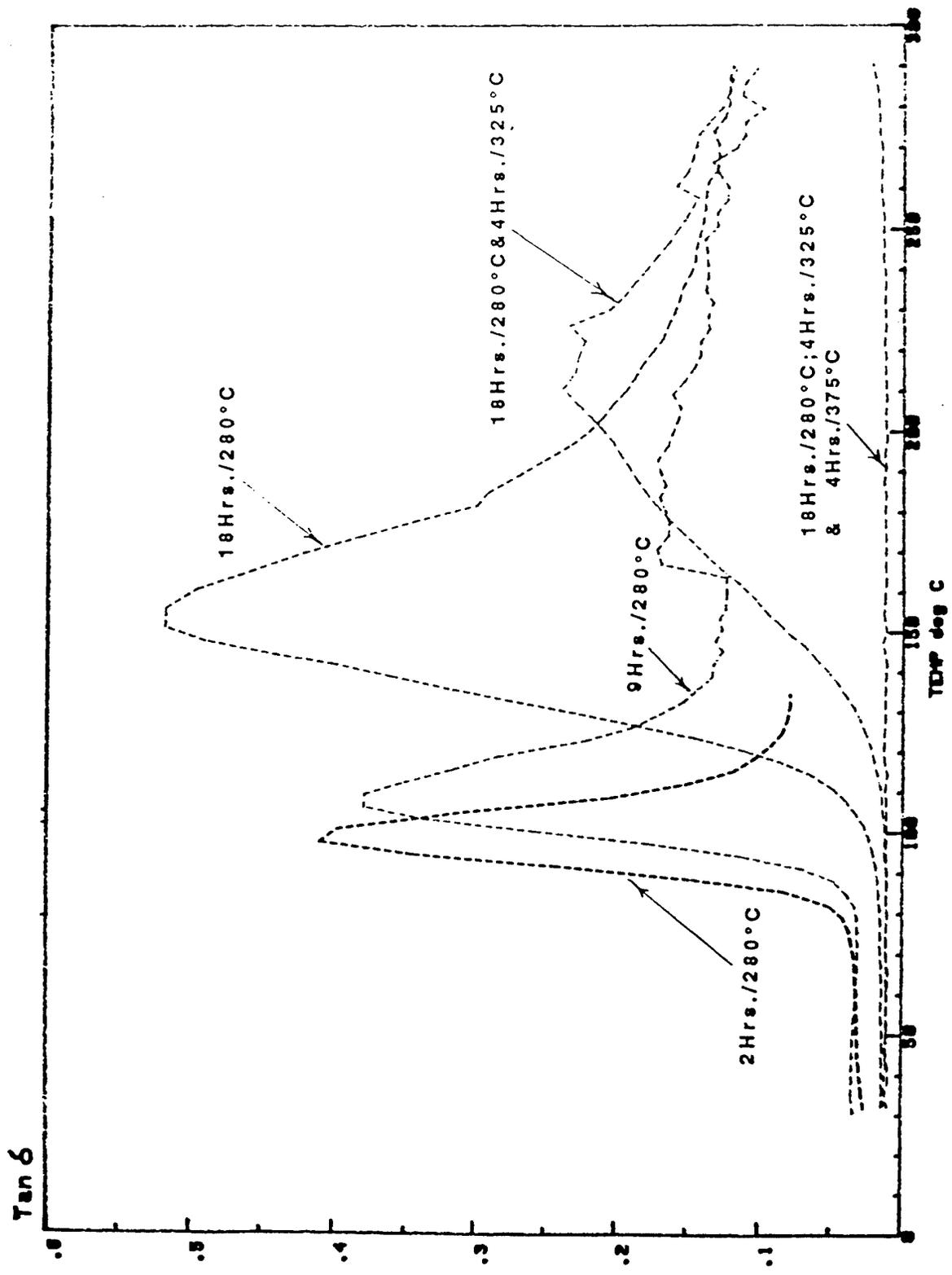
15 the invention may be practiced otherwise than as
16 specifically described.

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Inventor's Name: Imam et al.

PATENT APPLICATION

ABSTRACT

Metal foams are impregnated with a phthalonitrile prepolymer. The metal foam/polymer composite formed upon curing has excellent acoustic damping, structural properties, and flame resistance. Foams of various metals, such as aluminum, titanium, nickel, copper, iron, zinc, lead, silver, gold, platinum, tantalum, and alloys based on these metals may be used.



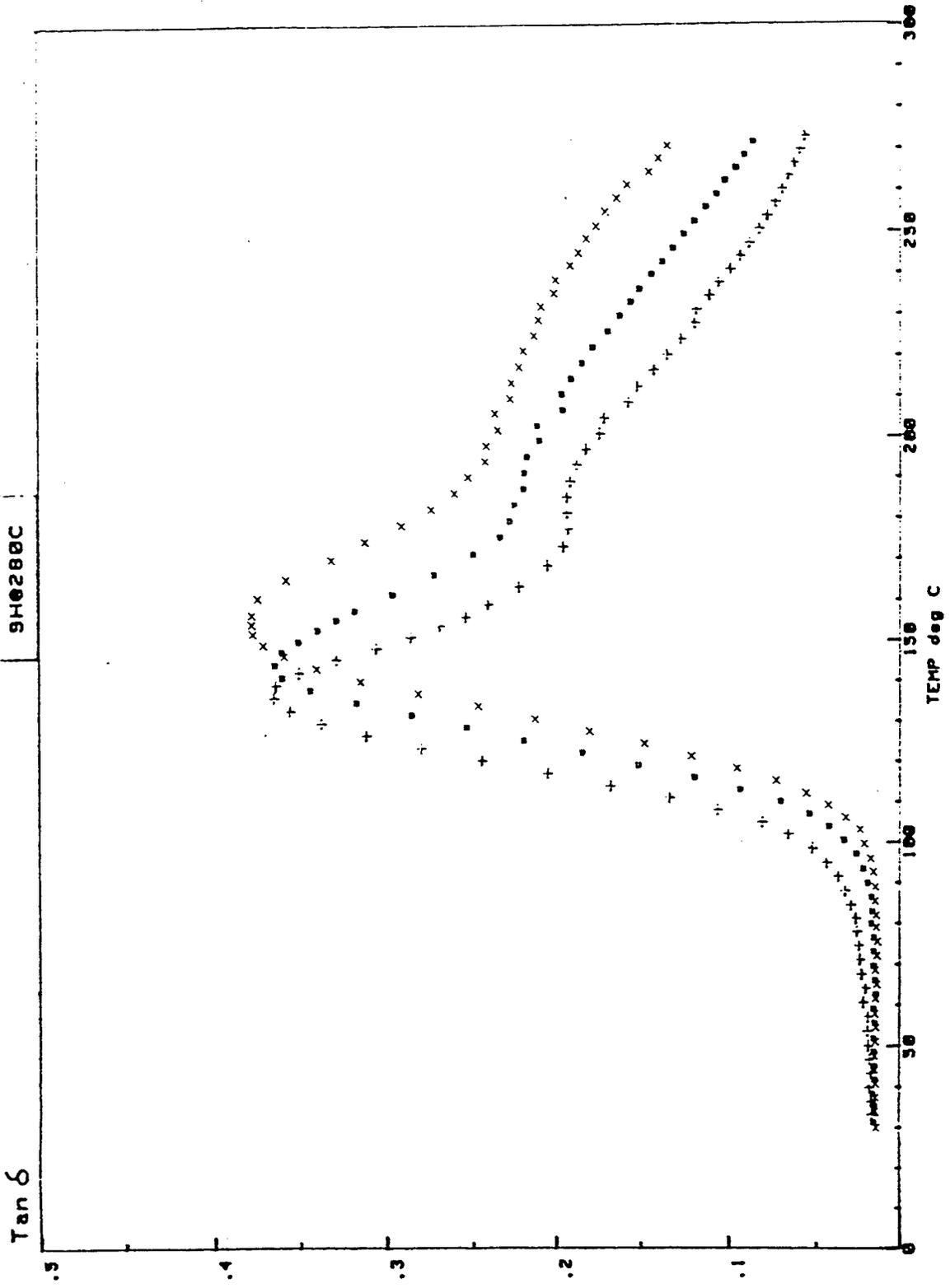
PL DMTA

0.1, 1 & 10
STRAIN = 4
2 DEG/C/min
-LOCK = 2.510
DUAL CONT
4.588980832111mm

--- 1 Hz

Fig 1

Cu-Ph
9H0280C



PI
DMTA

x 10 Hz
square 1 Hz
+ 0.1 Hz

0.1, 1 & 10
STRAIN = 4
2 degC/min
-LOGs = 2.62
DUAL CANT
1.49x9.98x7mm

Fig. 2

Cu-Ph
16H0280C; 4H0325C

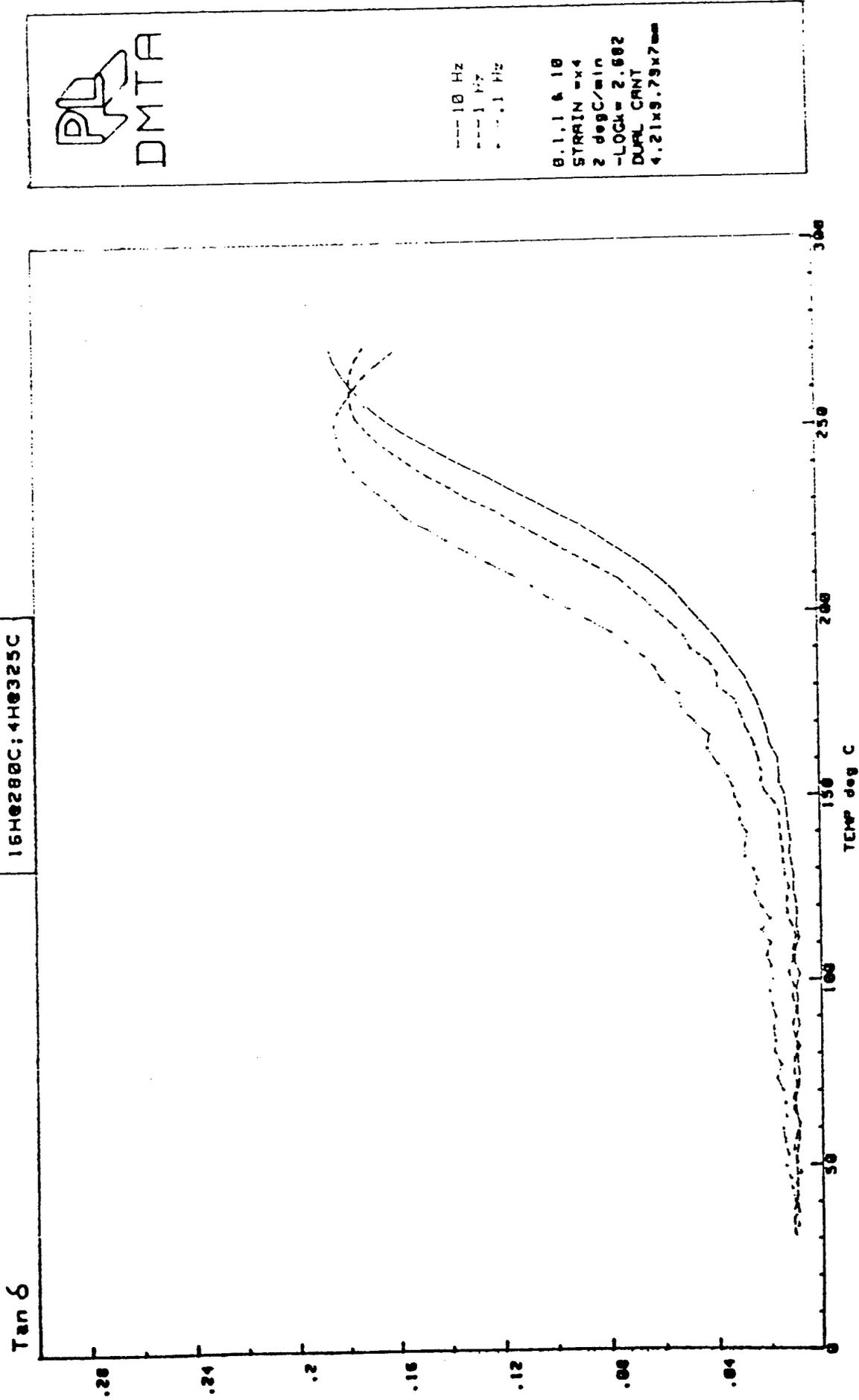
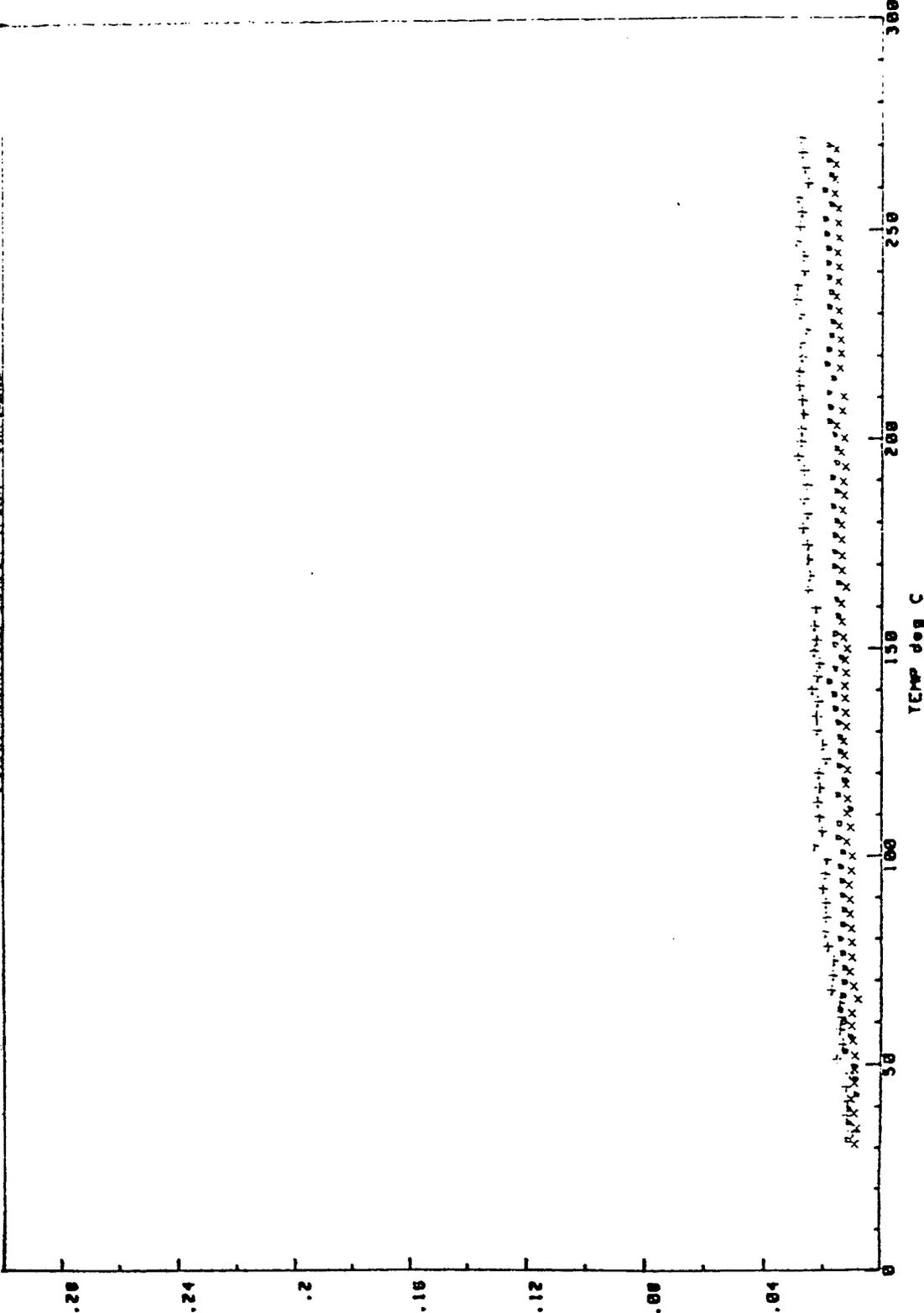


Fig. 3

Cu-Ph
16H0280C; 4H0325C; 4H0375C

Tan δ



PLD
DMTA

x 10 Hz
□ 1 Hz
+ .1 Hz

0.1.1 & 10
STRAIN = 4
2 degC/min
-LOCK = 2.583
DUAL CPMT
4.21x9.77x7mm

Fig. 4

Ti-Ph
9H0280C

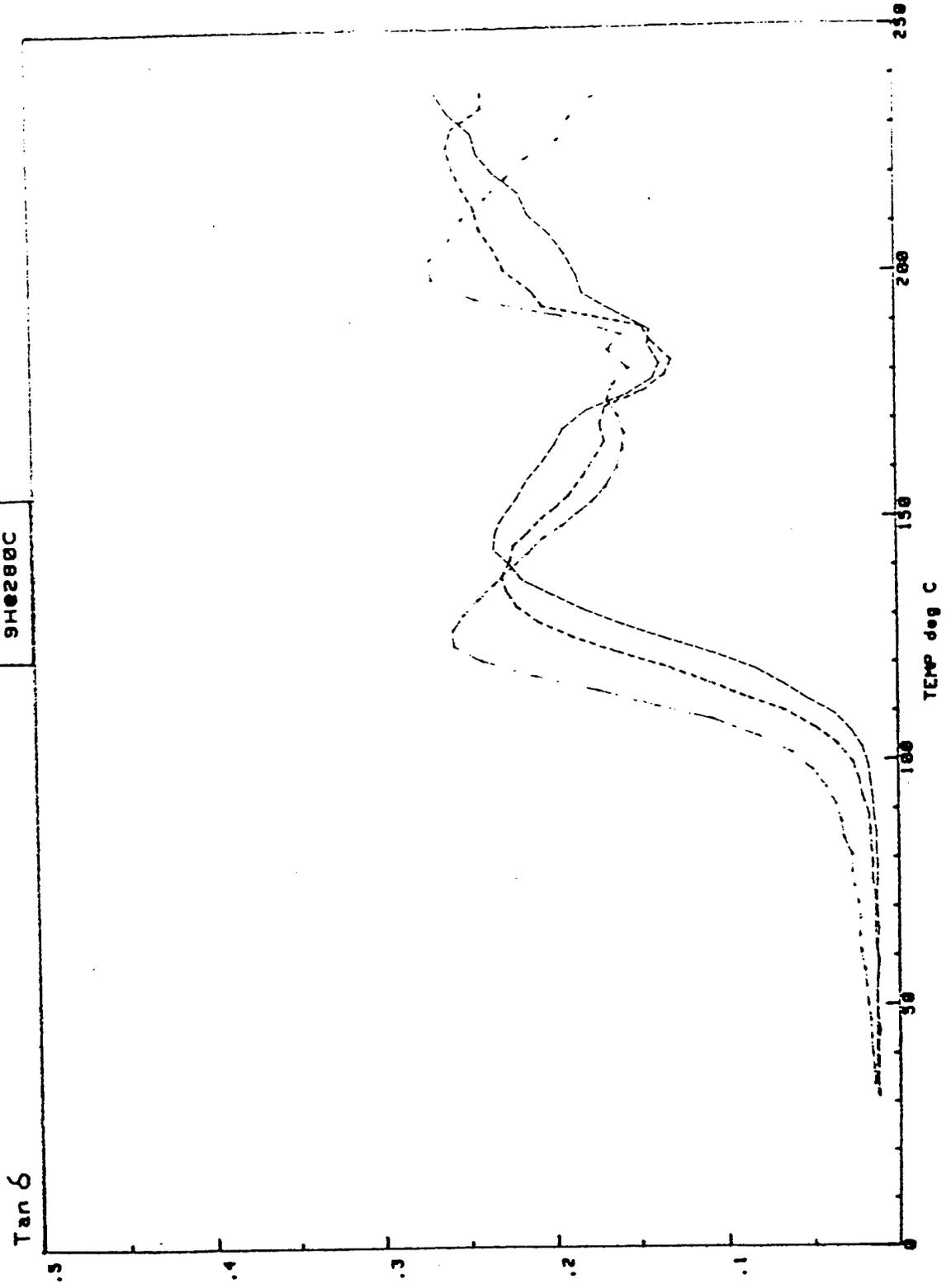
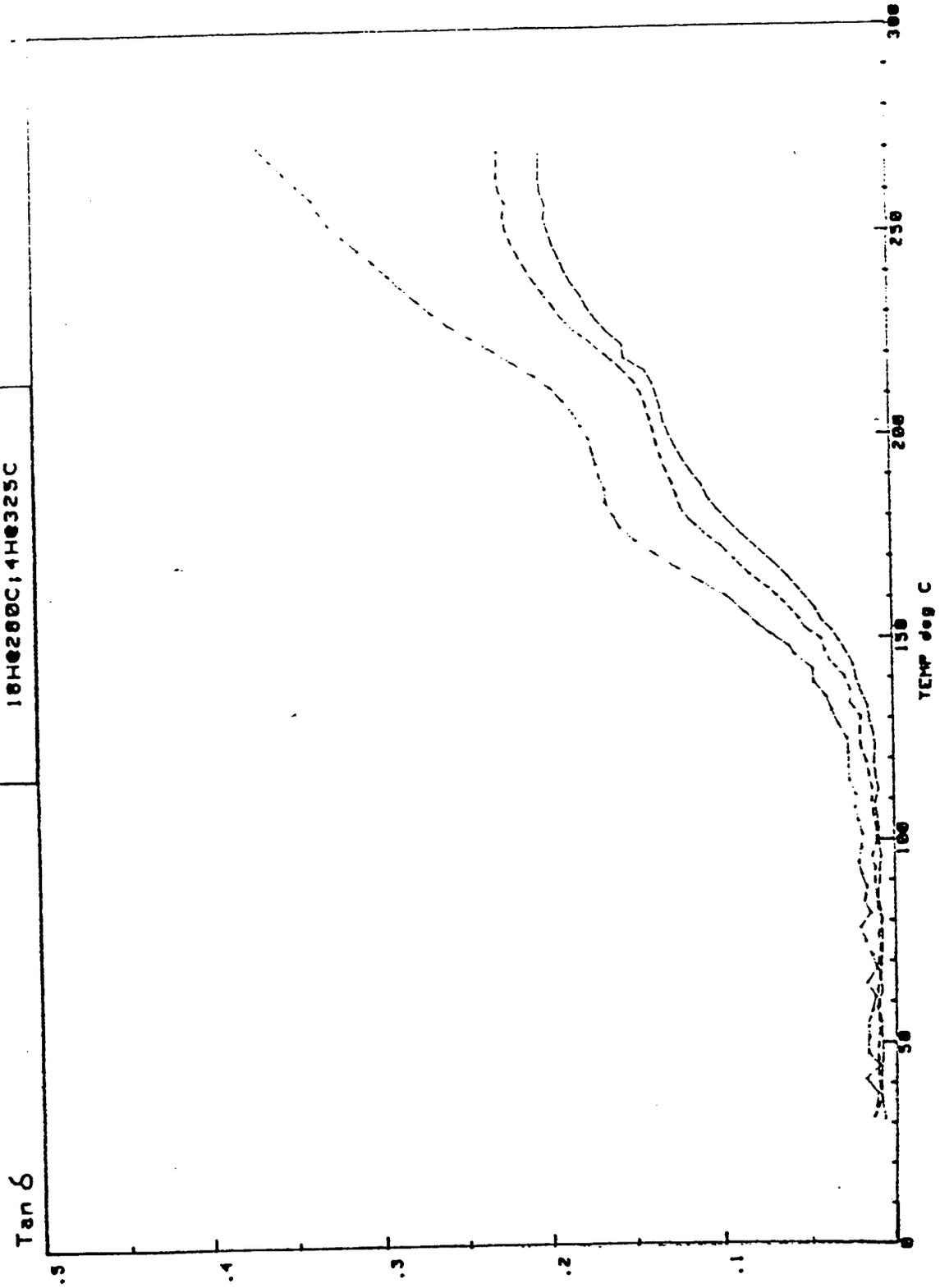


Fig. 5

Ph/T1 Composite
10H0200C;4H0325C



DMTA

--- 10 Hz
... 1 Hz
- · - · 0.1 Hz

0.1, 1 & 10
STRAIN = 4
2 degC/min
-LOGk = 2.015
DUAL CPANT
4.51x10x7mm

Fig. 6

Ph/Ti Composite
18H0280C;4H0325C;4H0375C

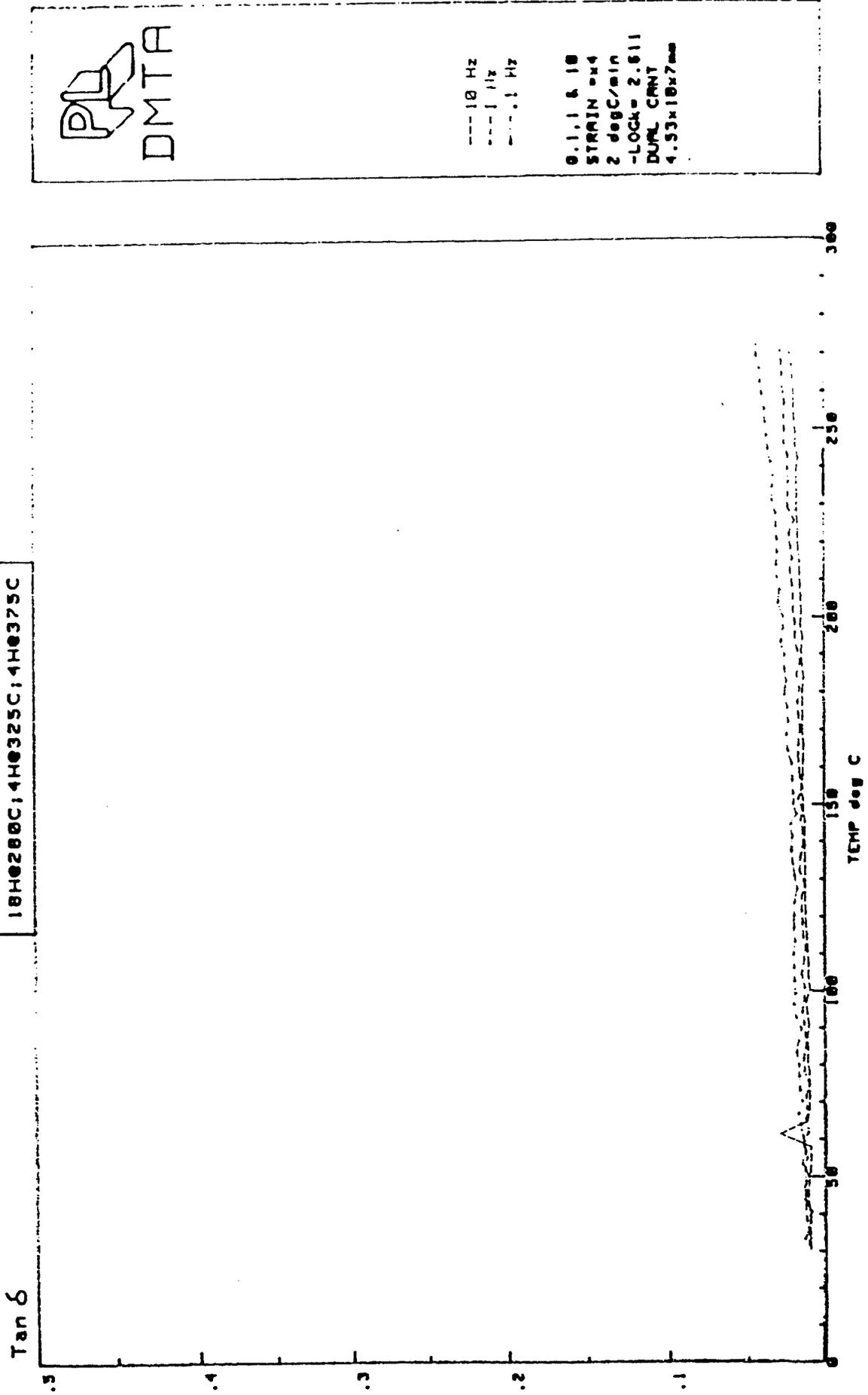
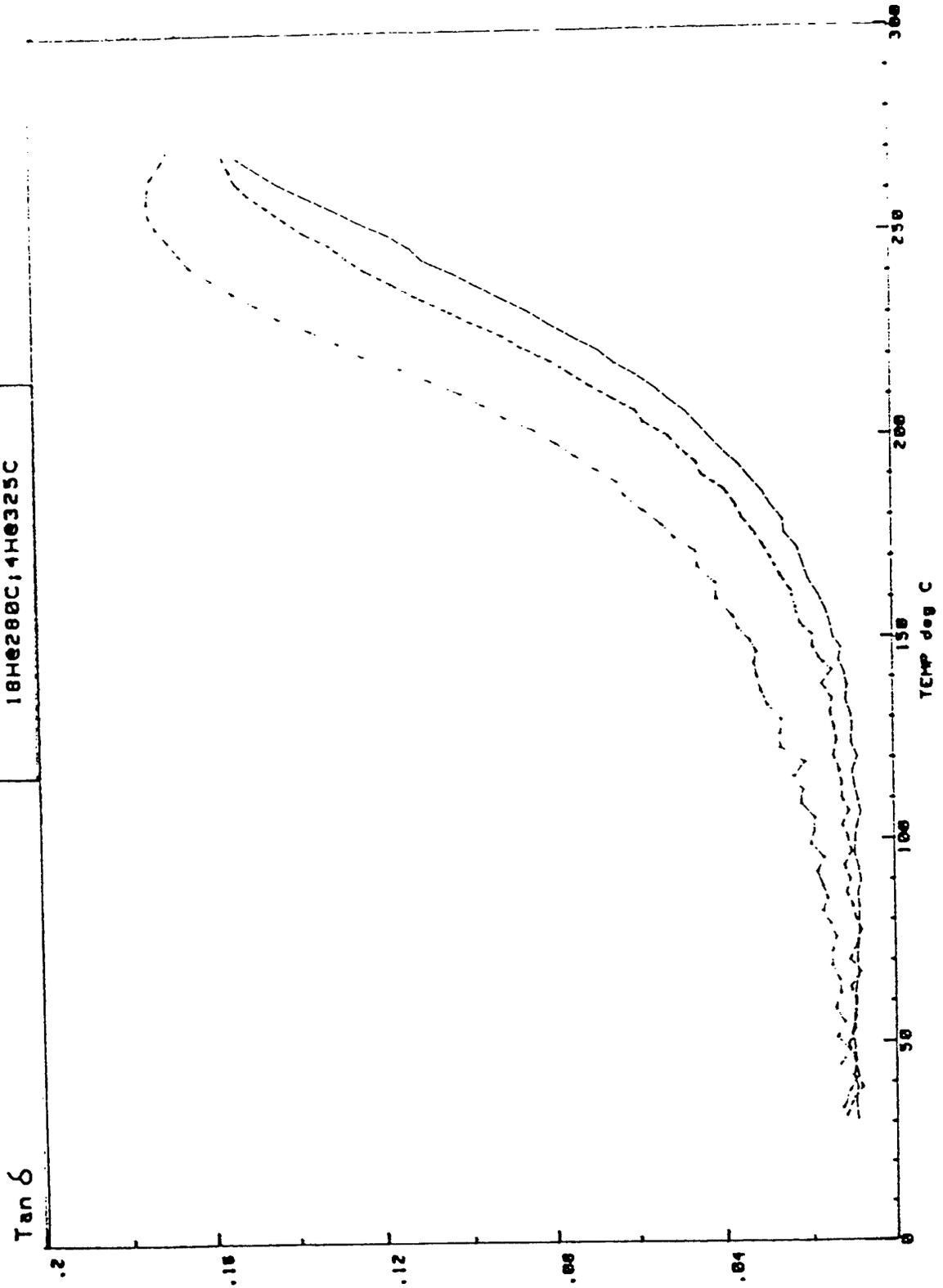


Fig. 7

Ph/Zn Composite
18He280C;4He325C



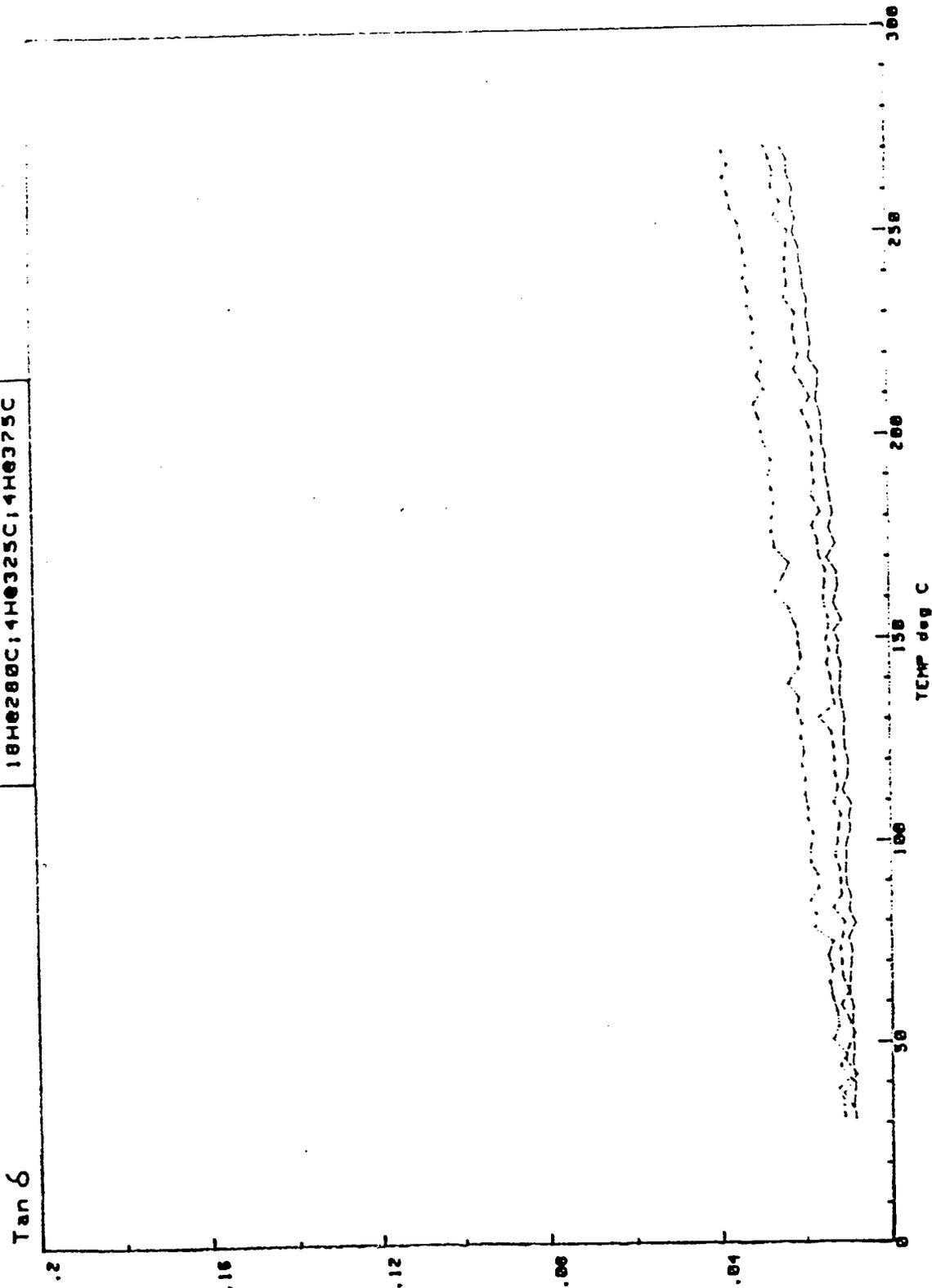
DMTA

--- 10 Hz
... 1 Hz
- . - . 0.1 Hz

0.1, 1 & 10
STRAIN = 4
2 degC/min
-LOCK = 2.615
DUAL CPMT
4.51x18x7mm

Fig. 8

Ph/Zn Composite
18H0280C;4H0325C;4H0375C



 DMTA

--- 10 Hz
... 1 Hz
-.- 0.1 Hz

8.1, 1 & 10
STRAIN = x4
2 degC/min
-LOGA = 2.615
DUAL CANT
4.51x10⁻⁷mm

Fig. 9

Tan δ Over Frequency Range of 0.1 to 10 Hz

