

INVESTIGATION OF COEFFICIENT OF THERMAL EXPANSION OF EPOXY GRANITE

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Abstract – The objective of the work is to establish simplified measuring method for measuring of coefficient of thermal expansion of various engineering and non-engineering material. CTE refers to the change in the size of a material when exposed to variations in temperature without undergoing any phase transitions. A thermomechanical analysis device is Designed and developed to determine the linear thermal expansion of a solid material during a constant heating process. The set-up recorded the alterations in the length of the specimen as the temperature changed and calculated the coefficient of linear thermal expansion based on the data obtained. The experiment was carried out on an aluminum sample. Application of this device is measurement of CTE of different material in industry and institute for study purpose.

Key Words: Thermo-mechanical properties, Coefficient of thermal expansion (CTE), Thermo-mechanical analysis, Aluminum.

1.Introduction

Materials exhibit thermal expansion and contraction phenomena within a specific temperature range devoid of phase transitions, such as melting or boiling. This thermal property gives rise to the observed effect of railway tracks exerting lateral pressure against each other during diurnal heating by solar irradiation, followed by nighttime contraction due to cooling. Consequently, this thermo-mechanical behavior presents a significant safety concern, potentially leading to catastrophic train derailments. In order to mitigate this inherent risk, standard railway track installation involves the deliberate introduction of a separation gap between track segments to accommodate and compensate for the inherent thermal expansion and contraction characteristics of the materials involved.

The phenomenon of altering dimensions in a solid in response to variations in temperature is denoted as the thermal expansion of solids. This physical property holds notable significance as it exerts a pronounced influence on the thermal stability of crystalline structures. In the realm of contemporary technology, the incongruities in lattice structures assume paramount importance and bear a direct correlation with the thermal expansion characteristics of materials. Precise and comprehensive thermal expansion data is of critical importance, particularly in the context of converting specific heat at constant pressure (C_p) to specific heat at constant volume (C_v). Aluminum, distinguished for its relatively elevated coefficient of thermal expansion among metals,

stands as a favored material for the empirical investigation and analysis of this property. [1]. The ubiquitous utilization of stainless steel across diverse applications renders it a routinely examined material. Overlooking its thermal response characteristics during engineering and design phases may engender catastrophic structural failures in critical infrastructures such as bridges or incur substantial expenses in the form of equipment damage. Despite the inherent complexities thermal expansion introduces into construction and design paradigms, a plethora of methodologies and advanced technologies have been innovated to systematically integrate thermal expansion as an indispensable facet within their operational frameworks. [2].

The coefficient of thermal expansion stands as a pivotal consideration when effecting the fusion of two dissimilar metals characterized by divergent thermomechanical properties. Substantial disparities in thermal expansion coefficients between adjacent metals, particularly during the cooling phase, can induce tensile stresses within one metal and concurrent compressive stresses within the other. The metal subjected to tensile stress may succumb to fracturing either during the welding operation or during subsequent service conditions, unless these stresses are systematically mitigated through thermal or mechanical modalities. Moreover, the thermal expansion factor assumes paramount significance in joints that experience cyclic exposure to elevated temperatures. In such contexts, a comprehensive appreciation of the coefficient of thermal expansion becomes indispensable. This necessity becomes particularly pronounced in components composed of hybrid material compositions, exemplified by heat exchangers featuring mild steel shells conjoined with austenitic grade tubes, where the interplay of distinct thermal expansion characteristics necessitates meticulous consideration and management. [3]. The thermal expansion property assumes paramount significance in the realm of casting electrical components, notably in the fabrication of transformer bushings and coils. Substantial disparities in the coefficients of thermal expansion between materials involved can precipitate deleterious outcomes, encompassing structural cracking or suboptimal adherence to conductive elements, thereby predisposing the assembly to oil leakage incidents. [4].

2. Methodology

2.1. Coefficient of Thermal Expansion (CTE)

- The Coefficient of Linear Thermal Expansion (CTE) is defined as the alteration in length, relative to the initial length of the specimen, per unit change in temperature, occurring at a specified reference temperature point.
- In a succinct technical definition, thermal expansion represents the dimensional variation observed in a material as a consequence of alterations in temperature.

2.1.1. Different methods which are available for measuring CTE

- Dilatometry
- Interferometry
- Thermomechanical analysis.

2.1.2. Comparison of the different methods

Comparison between different methods is shown in table no. 1 [5]

Table 1. Comparison of the Different Methods

Sr no	Type of method	Working Principle	Applicable Criteria
1	Dilatometry	The specimen is subjected to controlled heating within a furnace, and the resulting displacements at the extremities of the specimen are subsequently conveyed to a sensor via a system of push rods.	The lower threshold for the Coefficient of Linear Thermal Expansion (CTE) achievable through this methodology stands at 5×10^{-6} per Kelvin, within a temperature span ranging from -180 to 900 degrees Celsius.
2	Interferometry	The measurement of the displacement occurring at the ends of the specimen is quantified in units of the number of wavelengths of monochromatic light.	The upper threshold for the Coefficient of Linear Thermal Expansion (CTE) attainable through this methodology stands at 5×10^{-6} per Kelvin, primarily pertinent to materials characterized by low or negative CTE values. This measurement regime encompasses a temperature spectrum ranging from -150 to 700 degrees Celsius.
3	Thermomechanical analysis	This apparatus comprises a specimen holder and a probing mechanism responsible for	The lower threshold for the Coefficient of Linear Thermal Expansion (CTE)

		conveying alterations in specimen length to a transducer, which, in turn, converts the probe's displacements into an electrical signal.	achievable through this approach is established at 5×10^{-6} per Kelvin, encompassing a temperature range spanning from -120 to 600 degrees Celsius.
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2.1.3. Reasons to Choose thermomechanical analysis

The selection of thermomechanical analysis as the preferred method is predicated upon several key considerations:

- Dilatometry, as an alternative, exhibits diminished precision levels and necessitates the utilization of a furnace for specimen heating, which introduces limitations in terms of accuracy and practicality.
- The Interferometry method, while offering superior precision, imposes substantial initial capital investment requirements, making it less feasible from a cost perspective.
- Thermomechanical analysis, in contrast, does not demand a significant upfront financial outlay. Additionally, it aligns with our requirement for a portable instrumentation setup, a criterion that it readily fulfills, enhancing its overall suitability for our specific analytical needs.

2.2. Design methodology

The employed testing methodology leverages thermomechanical analysis as the principal technique for quantifying the linear thermal expansion characteristics of solid materials under the influence of a uniform heating rate [5]. This method entails the precise recording of alterations in the specimen's length relative to temperature variations, facilitating the subsequent derivation of the coefficient of linear thermal expansion from the acquired temperature-displacement dataset.

The primary objective of this experimental configuration revolves around subjecting the specimen to a controlled heating process within an open environment, concurrently monitoring its expansion through the application of a Dial gauge. Furthermore, this approach can be adapted for the purpose of systematically cooling the specimen, enabling the comprehensive characterization of its contraction behavior under varying thermal conditions. The CAD design of the CTE setup is shown in figure. 1

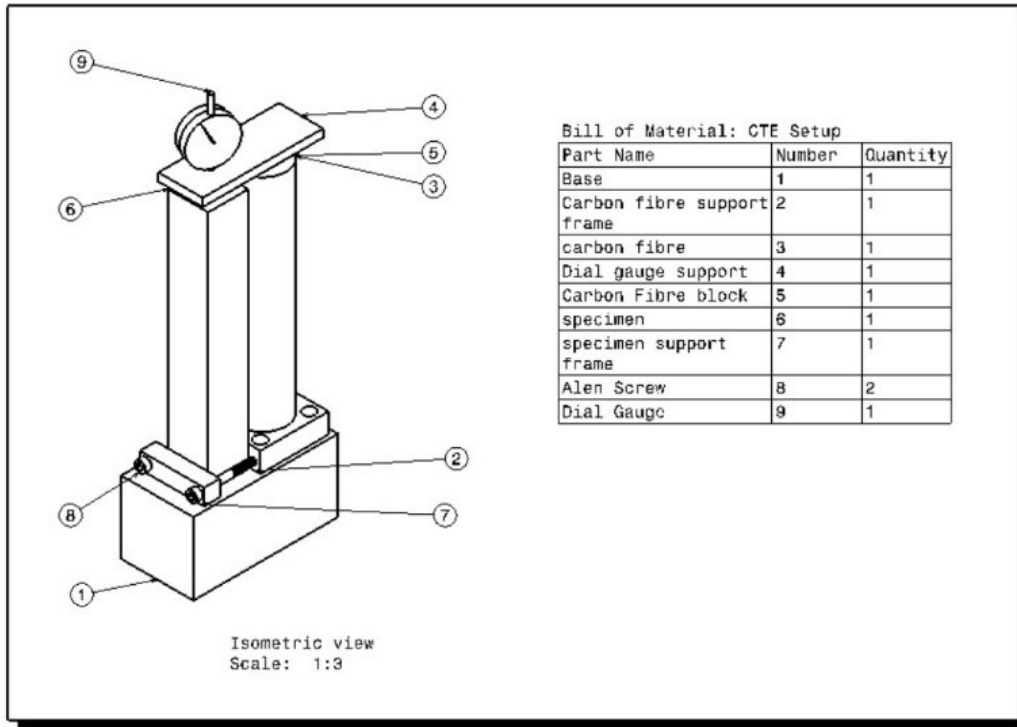


Figure 1. CAD Design

2.2.1. CTE setup consists of following parts:

1. Base:

The base of the setup is constructed from granite and serves as the support for the entire setup. Its dimensions are 180x90x90 mm.

2. Carbon Fiber support frame:

The carbon fiber support frame is made of carbon fiber and is used to adjust the height of the cylindrical carbon fiber. Its dimensions are 95x80x20 mm.

3. Cylindrical Carbon Fiber:

As the name implies, the cylindrical carbon fiber is made of carbon fiber. Carbon fiber was chosen because it has a zero coefficient of thermal expansion, making it ideal for attaching the Dial gauge and eliminating measurement error. The cylindrical carbon fiber has a 60mm radius and 300mm height.

4. Dial Gauge support:

The dial gauge support is made of carbon fiber and is used to secure the Dial gauge. Its dimensions are 150x55x10 mm.

5. Carbon fiber block:

The carbon fiber block is made of carbon fiber and serves as a mounting point for the carbon fiber holder. Its dimensions are 35x35x10 mm.

6. Specimen:

The workpiece should have a height of 300mm to match the height of the cylindrical carbon fiber, which is 300mm.

7. Specimen support frame:

The specimen support frame is made of mild steel and is used to secure the workpiece to the granite base. Its dimensions are 80x20x20 mm.

8. Alen Screw:

The M8 Alen screws are used to attach the specimen support frame.

9. Dial Gauge:

The Dial gauge is used to measure the expansion of the workpiece in microns.

10. Temperature Sensors:

Two temperature sensors are used, one to measure the temperature of the specimen and the other to measure the temperature of the environment.

2.3. Experimentation Procedure-

Table 2 depicts the experimental technique.

Table 2. Experimentation Procedure

1.	Begin the experiment.
2.	Assemble the arrangement in a well-lit location.
3.	Place the workpiece beneath the dial gauge in the specimen support frame.
4.	Place the specimen temperature sensor adjacent to the workpiece.
5.	Place the ambient temperature sensor in its proper place.
6.	Attach the dial gauge to the workpiece for measuring linear expansion.
7.	To guarantee contact with the workpiece, provide a proper load force to the dial gauge probe.
8.	Record the ambient temperature, specimen temperature, and dial gauge reading as the temperature is increased and decreased.
9.	Continue until the maximum temperature is attained.
10.	Make a graph of the data for expansion vs. temperature and contraction vs. temperature.
11.	Using the appropriate formula, calculate the coefficient of linear thermal expansion from the shown data.
12.	The experiment has come to an end.

2.3. Experimental Data-

Experimental data is shown in Table 3 and 4

Table 3. Expansion Experimental Data

Specimen Temp	expansion	Env. Temp	Time(min)
28	0	35.2	0
31	8	34.8	10
33	18	32.8	20
34	29	35.3	30
37	41	34.9	40
38	48	33.8	50
38	55	33.5	60
40	61	34.9	70
40	65	34.8	80
40	69	33.7	90
40	71	34.3	100
40	71	32.6	110
40	71	32	120

Table 4. Contraction Experimental data

Specimen Temp	Contraction	Env. Temp	time(min)
38	71	32	0
38	67	30.3	10
37	63	29.8	20
36	60	29.3	30
35	55	28.9	40
34	50	27.8	50
33	45	27.5	60
32	42	26.7	70
31	37	26	80
30	32	25.7	90
30	28	25.3	100
30	24	25.5	110
29	21	25.7	120

2.4. Calculations

Calculate the mean coefficient of linear thermal expansion for a desired temperature range as follows [8],

$$\alpha_m = \frac{\Delta L_{sp} \times k}{L \times \Delta T} \quad (1)$$

$$k = \frac{\alpha_{ref} \times L_{ref} \times \Delta T_{ref}}{\Delta L_{ref}} \quad (2)$$

where,

α_m = mean coefficient of linear thermal expansion, $\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$,

α_{ref} = mean coefficient of linear thermal expansion, for reference material $\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$,

k = calibration coefficient

L = specimen length at room temperature, m,

ΔL_{ref} = change of reference material length due to heating, μm ,

L_{ref} = reference material length at room temperature, m,

ΔL_{sp} = change of specimen length, μm ,

ΔT_{ref} = temperature difference over which the change in reference material length is measured, $^\circ\text{C}$

ΔT = temperature difference over which the change in specimen length is measured, $^\circ\text{C}$,

2.4.1. Calculation of CTE of Aluminum specimen:

i. Expansion

$$\alpha_m = \frac{\Delta L_{sp}}{L \times \Delta T}$$

$$\alpha_m = \frac{71}{0.3 \times 12}$$

$$\alpha_m = 19.72 \mu\text{m}/(\text{m} \cdot ^\circ\text{C})$$

ii. Contraction

$$\alpha_m = \frac{\Delta L_{sp}}{L \times \Delta T}$$

$$\alpha_m = \frac{54}{0.3 \times 9}$$

$$\alpha_m = 20 \mu\text{m}/(\text{m} \cdot ^\circ\text{C})$$

2.4.2. Calculation of Calibration Coefficient (k):

Calculating k by experimenting on Aluminum Specimen

$$k = \frac{\alpha_{\text{ref}} \times L_{\text{ref}} \times \Delta T_{\text{ref}}}{\Delta L_{\text{ref}}}$$

$$k = \frac{23.1 \times 0.3 \times 12}{71}$$

$$k = 1.166$$

3. Results

Aluminum is chosen as a reference material since its characteristics are widely understood. As a result of utilizing it as a standard, we were able to calculate the calibration coefficient (k). The precision of thermal expansion measurements is determined by the length of the specimen, the temperature range of interest, and the change in the length of the specimen.

We obtained the following results on aluminum specimens:

- While heating, the temperature of the aluminium ranges from 28°C to 40°C, and the largest expansion observed is 71 microns. While cooling, the temperature of the aluminium varies from 38°C to 29°C, and the maximum contraction seen is 54 microns.
- CTE of Aluminum while expansion is 19.72 $\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$ and while Contraction is 20 $\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$ versus standard CTE of aluminum is 23.1 $\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$ [5]
- From the results of Aluminum, we calculated the Calibration Coefficient which is 1.166
- In figure 2 temp vs expansion is shown, as temperature increases expansion in aluminium occurs.
- In figure 3 temp. vs contraction is shown, as temperature decreases contraction in aluminium occurs.

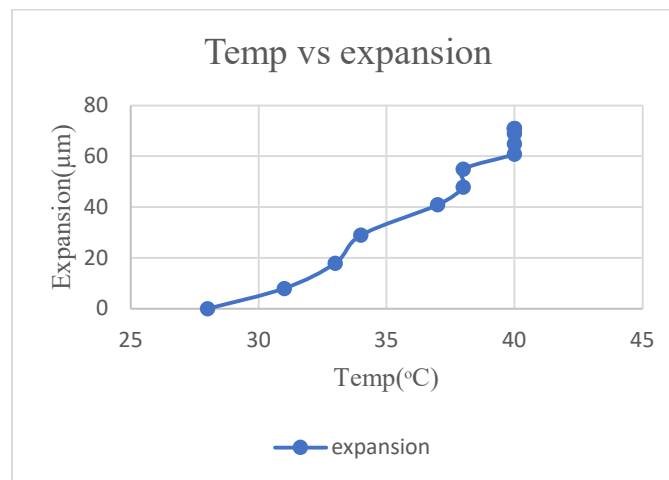


Figure 2. Temp vs Expansion

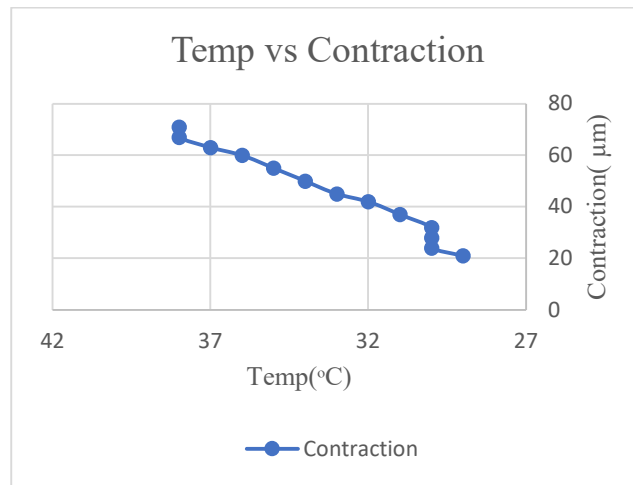


Figure 3. Temp vs Contraction

Based on the validation of the instrument and calibration coefficient epoxy granite specimens are tested, results are shown in below graphs

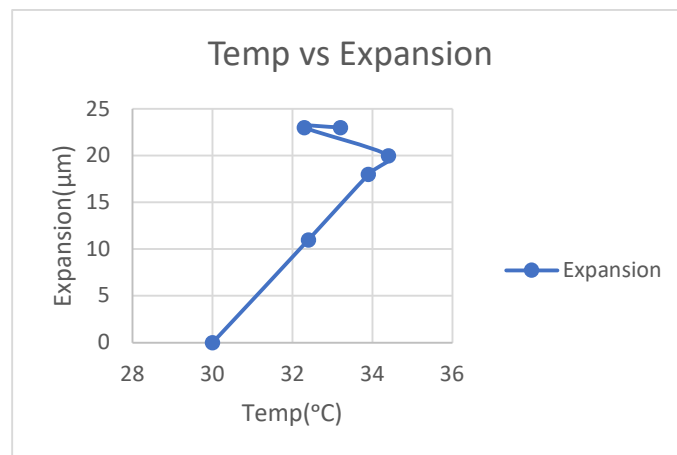


Figure 2. Temp vs Expansion of Epoxy-Granite Specimen

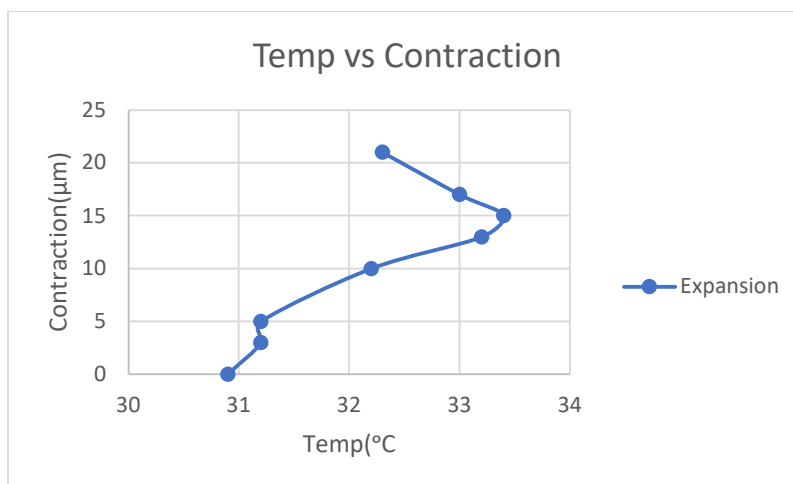


Figure 3. Temp vs Contraction of Epoxy-Granite Specimen

CTE of the Epoxy Granite material is in the range of 18 to 20 $\mu/\text{C-m}$. Slope of line while heating and slope of the line while cooling are different as the source of heating is direct sun light in daytime and rate of heating and cooling is different.

Based on the validation of the instrument and calibration coefficient epoxy granite specimens are tested, results are shown in below graphs

AI Specimen- Expansion Reading				AI Specimen- Contraction Reading			
Specimen Temp	Expansion	Env. Temp	Time(min)	Specimen Temp	Contraction	Env. Temp	Time(min)
28	0	35.2	0	38	71	32	0
31	8	34.8	10	38	67	30.3	10
33	18	32.8	20	37	63	29.8	20
34	29	35.3	30	36	60	29.3	30
37	41	34.9	40	35	55	28.9	40
38	48	33.8	50	34	50	27.8	50
38	55	33.5	60	33	45	27.5	60
40	61	34.9	70	32	42	26.7	70
40	65	34.8	80	31	37	26	80
40	69	33.7	90	30	32	25.7	90
40	71	34.3	100	30	28	25.3	100
40	71	32.6	110	30	24	25.5	110
40	71	32	120	29	21	25.7	120

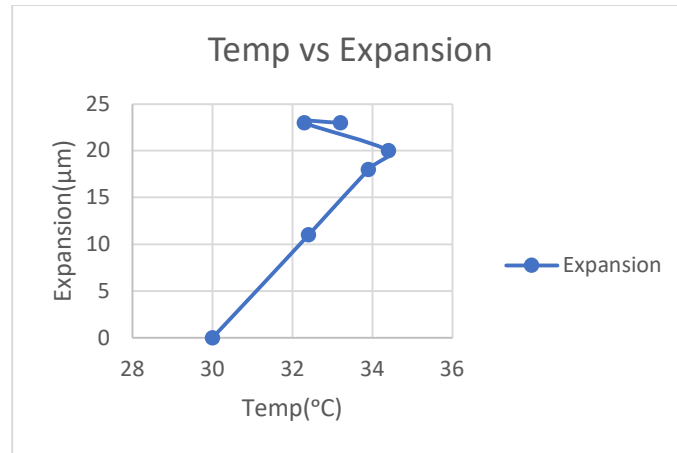


Figure 2. Temp vs Expansion of Epoxy-Granite Specimen

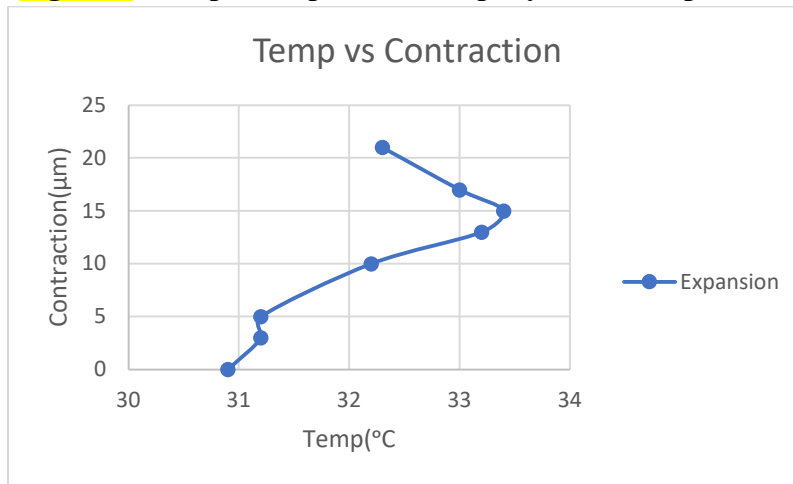


Figure 3. Temp vs Contraction of Epoxy-Granite Specimen

CTE of the Epoxy Granite material is in the range of 18 to 20 $\mu/^\circ\text{C}\cdot\text{m}$. Slope of line while heating and slope of the line while cooling are different as the source of heating is direct sun light in daytime and rate of heating and cooling is different.

4. Conclusions

- This way of computing CTE is simpler yet more effective than previous methods.
- The CTE equipment is portable, allowing us to measure the CTE of any material.
- We chose aluminum as a test material and conducted the experiment on aluminum specimens to validate the CTE setup.
- We obtained the Calibration coefficient from the testing on aluminum specimens, and we can use this to calculate the CTE of any material.

- **CONFLICT OF INTEREST -NIL**
- **SOURCE OF SUPPORT -NONE**

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