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# STUDY OF THE THERMO-PHYSICAL PROPERTIES OF POLYPROPYLENE/GRANITE PARTICULATES COMPOSITES AS DENTAL IMPLANTS

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**ABSTRACT**

This study focuses on the development of a composite material for potential dental applications by investigating the influence of granite particulate (GTP) loading on the physical properties of polypropylene (PP) matrix. This was achieved by washing the granite in distilled water, followed by drying and then ball milling for 72 hours. Subsequently, the powdered granite was combined with polypropylene (PP) in a two-roll mill compounder at a temperature of 150°C for 5 minutes. Five distinct samples with varying GTP percentages ranging from 10% to 50 wt. % were produced. The samples were thereafter subjected to testing for various physical properties such as density, thermal conductivity and diffusivity, specific heat capacity etc. Standard analytical techniques such as DSC and TGA were employed to analyze the sample. It was observed from the obtained results that sample containing 50 wt. % PP/GTP demonstrates enhanced properties of such as thermal degradation resistance of 75.23 % as compared to 94 % weight loss of the other tested weight ratios, thereby making it a choice candidate for potential applications in dentistry.

**Keywords**: Polypropylene (PP), Granite particulate (GTP), Physical properties, Dental Implants, Dentistry

## INTRODUCTION

The inherent properties of an engineering material will always influence its selection for adaptability in the field of dentistry (Dodo *et al.*, 2022). For instance, metals are primarily strong, stiff and hard, which influence their usage in any field of engineering. Hence, these properties would tend to recommend them as restorative materials in the dentistric field (Xiaoqing *et al.*, 2017). From a material standpoint, dental implants can be composed of polymers, metals, and ceramics. With regard to metals, titanium has established itself as the "gold standard" material for the manufacturing of endosseous dental implants due to its outstanding long-term clinical survival statistics (Adell *et al.*, 1990). In a similar vein, zirconia, a ceramic, is distinct from other oxide ceramics because of its exceptional physical characteristics, higher resistance to corrosion and wear, and high flexural strength in comparison to other dental ceramics (Denry, 2008; Prosthodontics, 2024). On one hand, polymers are biologically tolerable substances. They do not generate electrolytic current as do metals and they are more esthetically pleasing. However, they have inferior physical properties with lack of adhesion to living tissues and have adverse immunologic reactions (Prosthodontics, 2024). In certain situations, the replacement material should have the same appearance as teeth for proper esthetics. Thus, the material should be a good thermal insulator like enamel and dentin. Again, the material should not release toxic chemicals if by any means break down (Thepoint, 2024). Additionally, in choosing restorative materials, both labour and costs should be taken into account. We start to see that there are a wide range of characteristics that make up the perfect restorative material as the list of needs expands. However, there is no perfect material, thus we must constantly make some sort of compromise (Thepoint, 2024). It is always said that the specifications for a particular restoration for a certain tooth and patient is a key issue. Although it might be difficult to decide what is necessary and what will work best in a certain clinical setting. Usually, one strikes a compromise with the numerous variables under consideration (Thepoint, 2024). Therefore, this study aims at developing dental implant material with improved physical properties from polymer based composite made from polypropylene reinforced with granite particulates.

## MATERIALS AND METHODS

### Fabrication of PP/GTP Composite

Five samples of PP/GTP composite with different compositions of 10, 20, 30, 40 and 50 wt% were manufactured via the melt compounding technique using a Brabender mixer. The process initiated with the melting of the Polypropylene matrix, followed by blending it with the corresponding percentage of granite using roll mills, employing a heating temperature of 180°C, a processing time of 5 minutes, and a screw speed of 75rpm. The resulting melt (PP&GTP) was subsequently transferred to a hot press machine and processed into a composite at a temperature of 150°C for 5 minutes. The resulting samples were sized at 120 x 150 x 3 mm.

The samples were finally sectioned into suitable dimensions using hand saw and bench clamp for the various test to be carried out on the PP/GTP composites.

### Density Determination

The density of the different samples was determined by initially weighing the specimen masses, which were cut from the samples, in the laboratory using a digital balance. Subsequently, each specimen was suspended in water, and the volume of the samples was determined by measuring the volume of water displaced, considering it as the volume of the composite material. Finally, the density was computed using the following expression:

$$Density\ (p) = \frac{\boldsymbol{Mass\ (m)}}{\boldsymbol{Volume\ (v)}} \quad (1)$$

### Determination of Thermal Conductivity

The experimental setup involved connecting a voltmeter to the D.C. power supply unit's terminals, with the ammeter's positive terminal in series to it, and the negative terminal of the ammeter to one of Searle's apparatus terminals, while the other was connected to the D.C. power supply unit's negative

terminal. The water supply was adjusted to ensure a continuous flow around Searle's Apparatus. Once the D.C. power supply was activated, the sample dimensioned 30x30x10 mm was placed in Searle's Apparatus, yielding readings for voltage (V), current (I), and temperature difference (ΔT) from a sample-attached thermometer ($T_1$ and $T_2$). The sample's thickness and diameter were measured with a micrometer screw gauge and Vernier calipers, allowing for the calculation of cross-sectional area (A) using the formula $A = \pi r^2$. Finally, the sample's thermal conductivity (k) was computed using the relevant formula.

$$K = \frac{VIL}{A\Delta T} \quad (2)$$

Where; K = Thermal Conductivity, V = Voltage, I = Current, L = Length of Specimen, A= Area of Specimen, $\Delta T$ = Change in Temperature

**Specific Heat Capacity Determination**

Water was firstly poured into a beaker, which was then placed on top of a hot plate and subjected to heat. Subsequently, the sample was submerged in the hot water and allowed to reach its boiling point. At this stage, the calorimeter and stirrer were weighed, and the mass was recorded as M1. The calorimeter was filled halfway with cold water and reweighed as M2. The initial temperature of the cold water was measured and recorded as $T_1$, while the temperature of the boiling water was noted as $T_2$. The hot sample was swiftly transferred from the beaker into the calorimeter containing cold water, and gentle stirring ensued until the mixture reached its highest temperature, recorded as $T_3$. Following this, the calorimeter and its contents were weighed again, denoted as M3, to determine the mass of the sample. Subsequently, the specific heat capacity of the sample was calculated using the relationship provided in the equation below;

$$Cs = ((M1 \times Cc + Mw \times Cw)(T_3 - T_1)) / (Ms(T_2 - T_3)) \quad (3)$$

Cs= Specific Heat Capacity of the Sample, $M_1$= mass calorimeter and stirrer, Cc = Specific Heat Capacity of calorimeter, Cw = Specific Heat Capacity of water, Mw= mass of water, Ms= mass of sample, $T_1$ = Temperature of water $T_2$ = Temperature of boiling water $T_3$ = Temperature of mixture

**Thermal Diffusivity Determination**

The thermal diffusivity of the samples were determined by calculation using the samples densities, thermal conductivities and specific heat capacities. The equation below is used for the calculation of the thermal diffusivity.

$$Thermal\ diffusivity = \frac{k}{pc} \quad (4)$$

Where; $k$ = Thermal conductivity, $p$ = density, $c$ = specific heat capacity

**Thermogravimetric analysis**

A representative sample of the composite material measuring 10x10x3 mm is prepared and accurately weighed in a suitable sample pan. The sample pan is then placed within the TGA instrument, where the heating rate, temperature range, and gas atmosphere (typically nitrogen to prevent oxidation) are configured. The analysis is initiated, during which the sample undergoes controlled heating, and simultaneous weight changes are recorded by the instrument. The resulting TGA curve is then interpreted to identify crucial thermal events, such as decomposition temperatures, and to calculate the weight variations at specific temperature intervals.

**Differential Scanning Calorimetry**

Samples measuring 10x10x3mm were sectioned and utilized for the analysis. The PP/GTP composite sample (typically 5-20 milligrams) was weighed and placed into an aluminum DSC pan, ensuring a tight seal. A reference material (e.g., sapphire or indium) was similarly prepared. Both pans were loaded into the DSC instrument, connected to a computer with DSC software, and parameters like the heating rate (5-20°C/min) and temperature range were set. A baseline calibration was performed using an empty pan. The DSC analysis was initiated to simultaneously heat both pans, with heat flow recorded as temperature increased, resulting in the generation of a DSC thermogram revealing thermal events such as melting, glass transition and crystallization. The data were analyzed to determine properties like melting temperature ($T_m$), glass transition temperature ($T_g$) and reaction enthalpy, with results interpreted in the context of the material's behavior.

**RESULTS AND DISCUSSION**

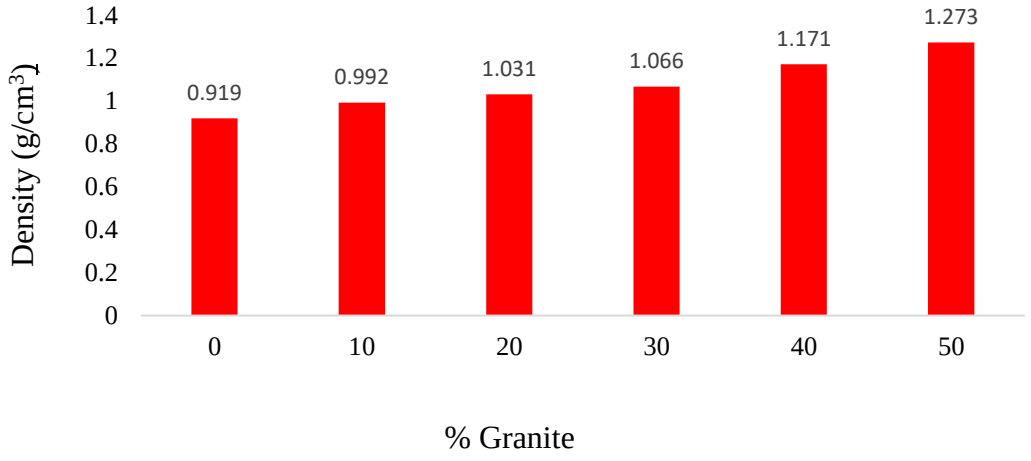



Figure 1: Variation of density with Wt. % Granite for the PP/GTP composites

Figure 1 revealed a clear trend in density with varying weight percentages of granite. As the weight percentage of granite reinforcement increases, the density of the composite surge mildly. Control has density of 0.919 g/cm³, while at 50% it reaches 1.273 g/cm³. This trend shows that addition of granite has a direct and progressive impact on increasing the density

of the composites. Similarly, (Pawar *et al.,* 2015) conducted a study on the effect of granite powder on polymer composites for wind turbine blades and observed an increase in the density of the composite as the percentage of granite powder increased. When selecting materials for dental applications, density plays a crucial role. Dental prosthetics and restorations should be of an appropriate density to ensure patient comfort and overall durability. It's worth noting that dental materials need to maintain a balance between density, strength, and aesthetics. Based on the result of this research, the PP/GTP composite with 40% granite particulate; has a density of 1.171 g/cm³, represents a promising candidate for dental applications. This composition offers a good compromise between the density required for durability and the need for ease of use and aesthetics.

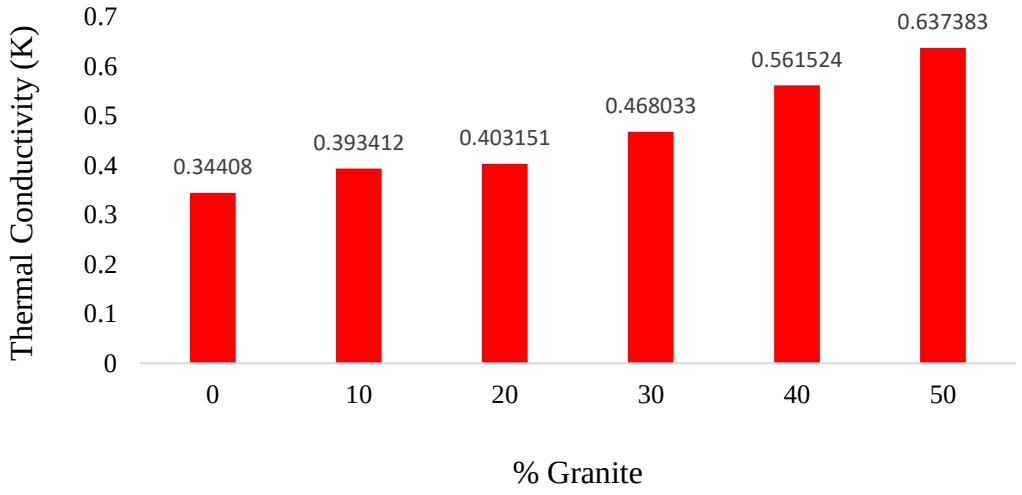



Figure 2: Variation of thermal conductivity with GTP addition

Figure 2 demonstrates that weight percentage of granite increment led a consistent and noticeable increase in thermal conductivity. It has been seen that at 0% granite, the thermal conductivity is 0.344080 W/mK. Further, at 50% addition, a significant rise to 0.637383 W/mK recorded. This observation indicates that addition of granite reinforcement leads to an increase in the thermal conductivity of the composite. Research by (Singh, 2014) on thermal conductivity of epoxy matrix composites filled with granite dust observed similar trend of increasing thermal conductivity as the weight percentage granite dust increases. Higher thermal conductivity can be advantageous for efficient heat dissipation. However, the optimal thermal conductivity value for dental applications should strike a balance between heat dissipation and insulation to prevent excessive temperature fluctuations in contact with oral tissues. Based on the data obtained, the composite material with 50% granite content exhibits the highest thermal conductivity. Still, a composition with 30% reinforcement, which has a thermal conductivity of 0.468033 W/mK, might offer a more balanced thermal performance, making it a potential candidate for dental applications.

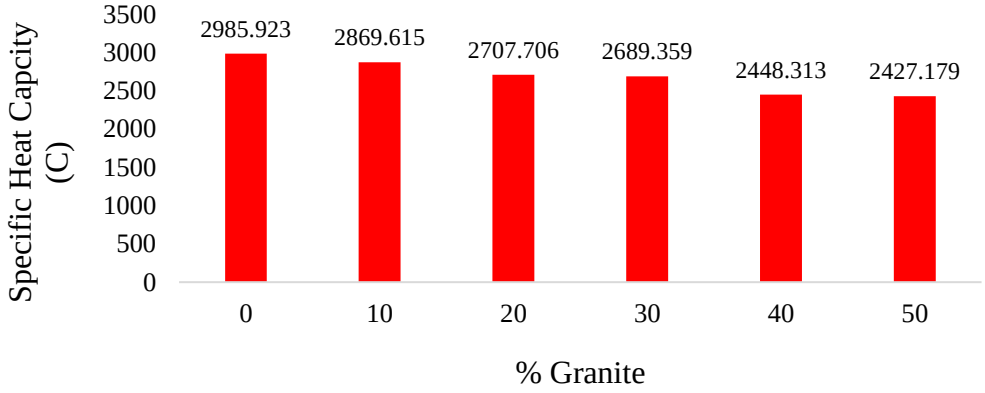



Figure 3: Variation of SHC with granite loading

Figure 3 clearly illustrates the influence of the proportion of granite on the specific heat capacity of the composites. There is a discernible trend in SHC with granite increase. At 0% granite, the SHC is 2985.923 J/kg·K, while at 50% addition, it decreases to 2427.179 J/kg·K. This trend indicates that granite results in a decrease in the SHC of the composites. Accordingly, neat PP (control) has the highest SHC, which might be disadvantageous for dental applications where heat retention is not important. Likewise (Dodo *et al.,* 2022) reported a progressive decrease in the specific heat capacity with the addition periwinkle shell particulates in PP matrix. The existing literatures (Brown *et al.,* 1970; O'Brrien, 1997) revealed an average value of the specific heat capacity of the whole human tooth to be 0.29 cal/g $^{o}$C (1214 J/kgK).

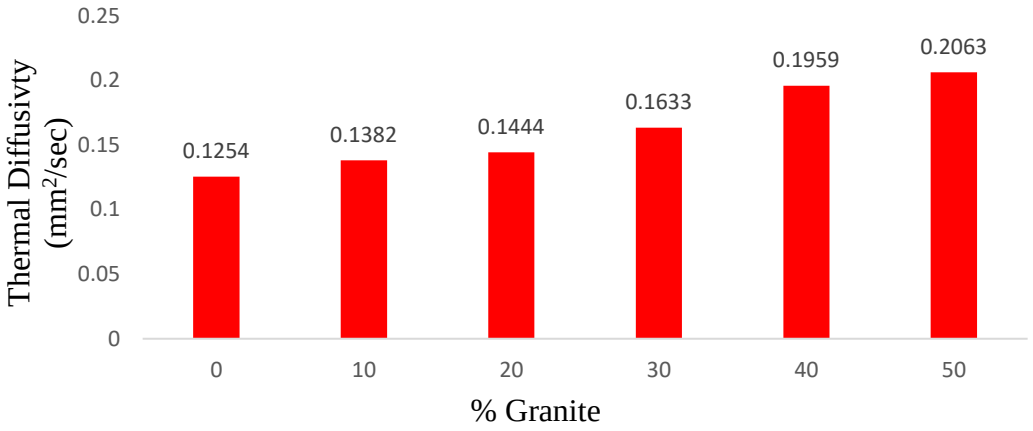
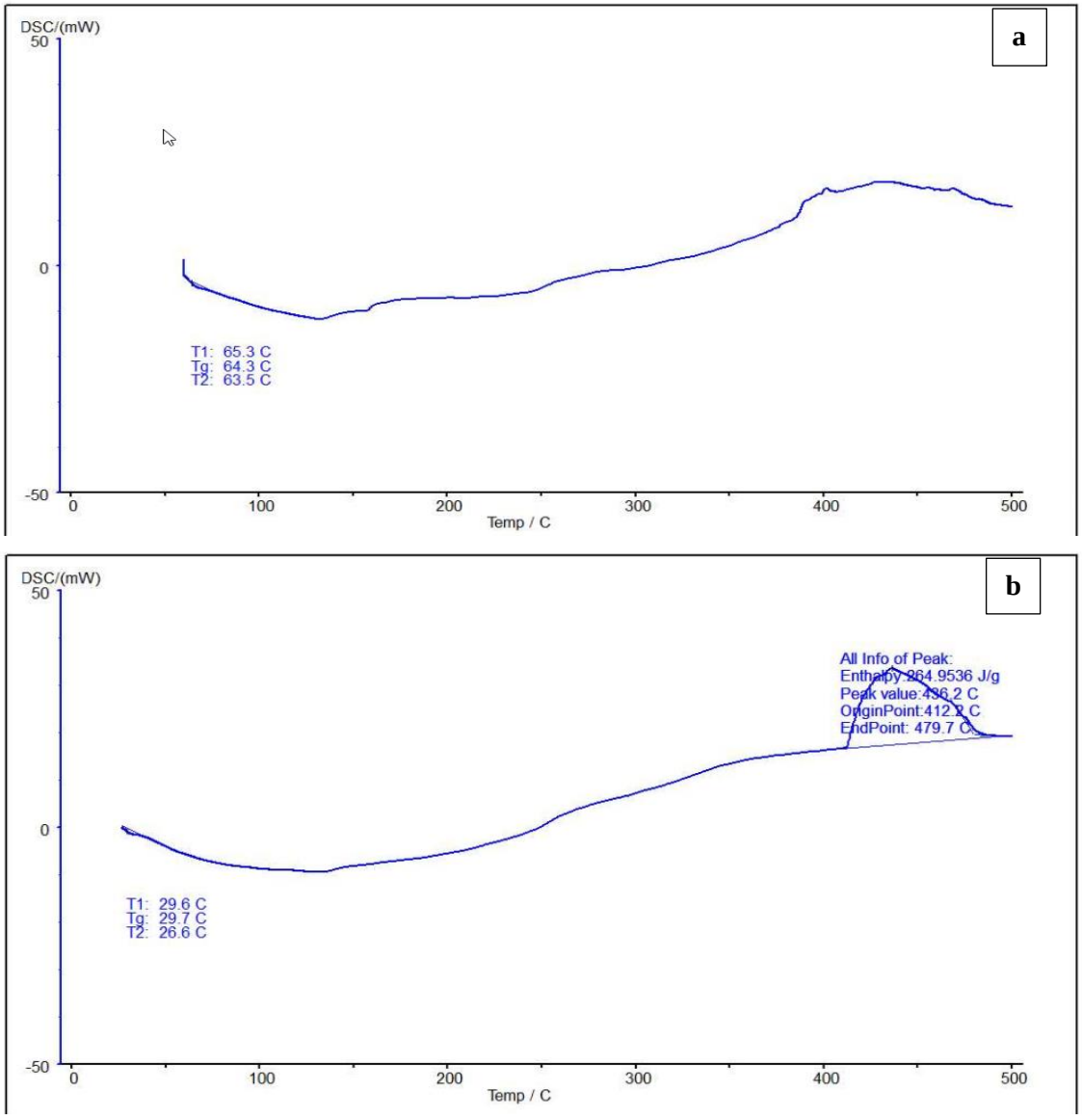
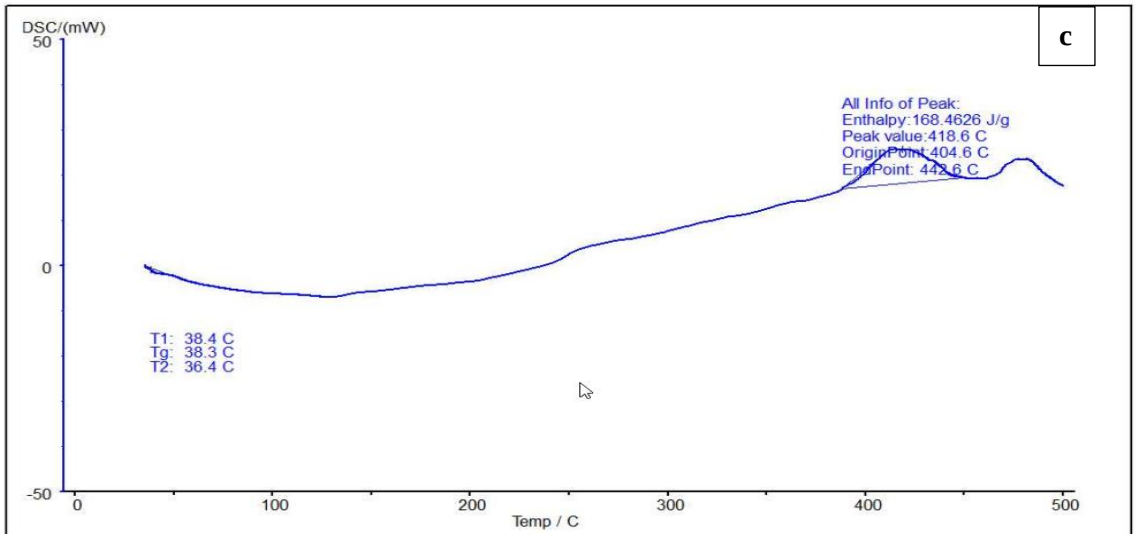



Figure 4: Variation of thermal diffusivity of the PP/GTP composites

Figure 4 provides a comprehensive dataset that clearly demonstrates the relationship between the weight percentage of granite addition and the corresponding thermal diffusivity in the composites. A discernible trend can be observed as the content of granite rises; the thermal diffusivity also shows a clear upward trajectory. For instance, at 0% granite reinforcement (control), the thermal diffusivity is 0.1254 $mm^2/s$, while at 50% addition, it significantly climbs to 0.2063 $mm^2/s$. This trend suggests that the addition of granite filler enhances the thermal diffusivity of the composites, indicating a quicker spread of heat.




c
DSC/(mW)
50
0
-50
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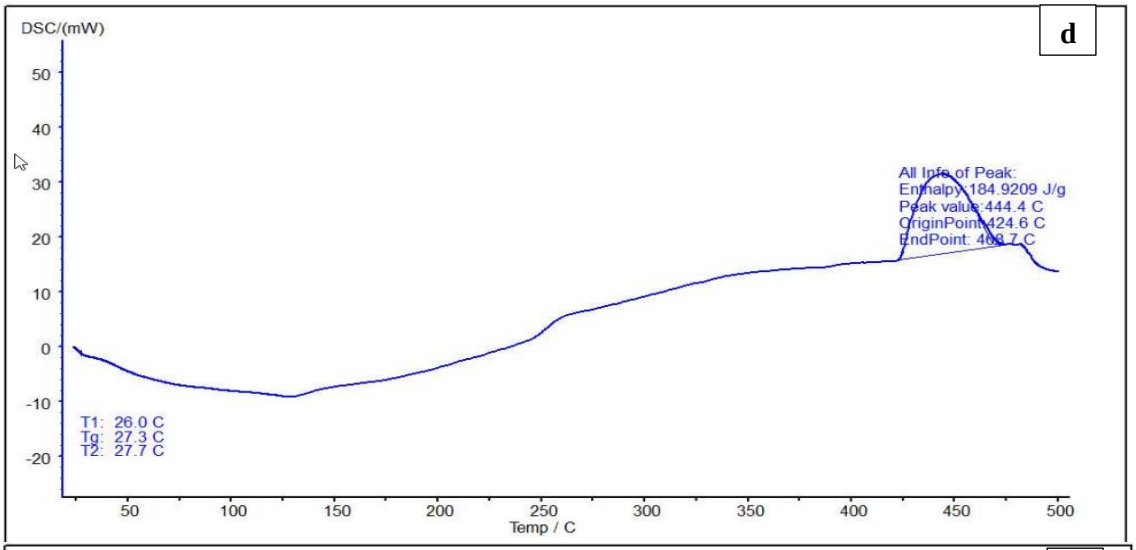
Peak value:418.6 C
OriginPoint:404.6 C
EndPoint: 442.6 C
T1: 38.4 C
Tg: 38.3 C
T2: 36.4 C
0
100
200
300
400
500
Temp / C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30
20
10
0
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-20
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OriginPoint:424.6 C
EndPoint: 468.7 C
T1: 26.0 C
Tg: 27.3 C
T2: 27.7 C
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150
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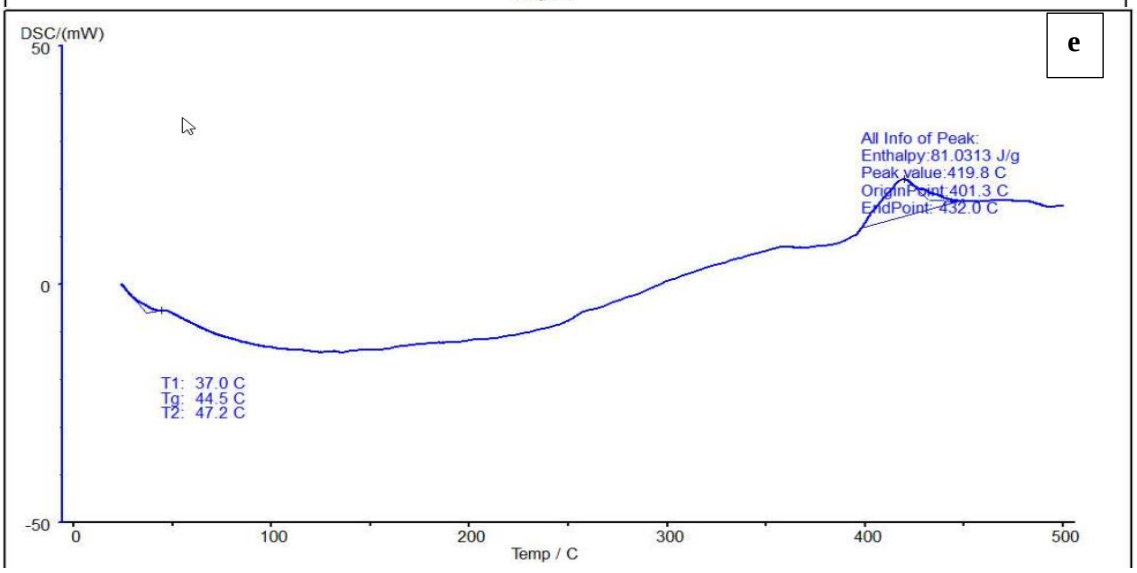
Temp / C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DSC/(mW)
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0
-50
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T2: 47.2 C
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100
200
300
400
500
Temp / C

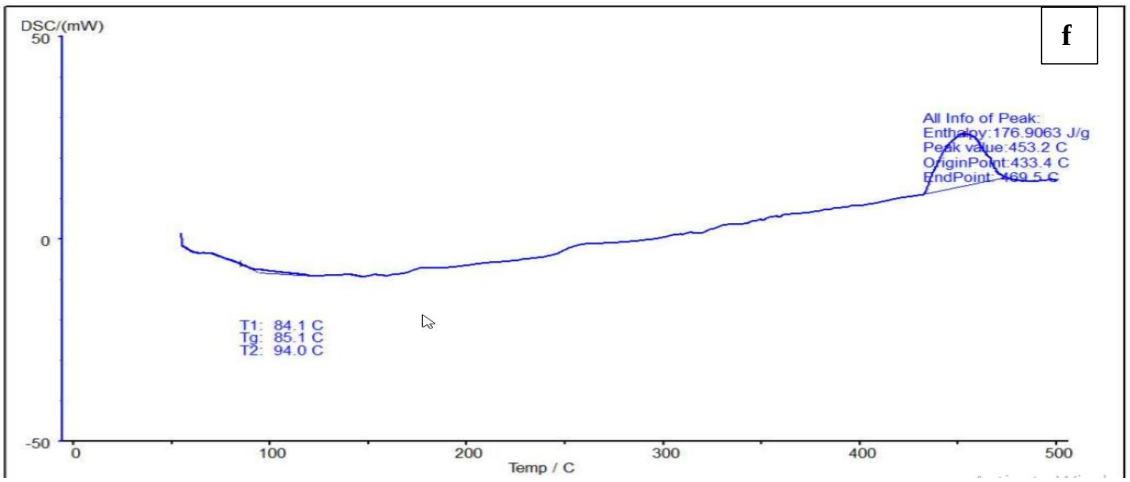


Figure 5: DSC curves of (a) neat PP (control) (b) PP/10 wt. % GTP (c) PP/20 wt. % GTP (d) PP/30 wt. % GTP (d) PP/40 wt. % GTP (e) PP/50 wt. % GTP

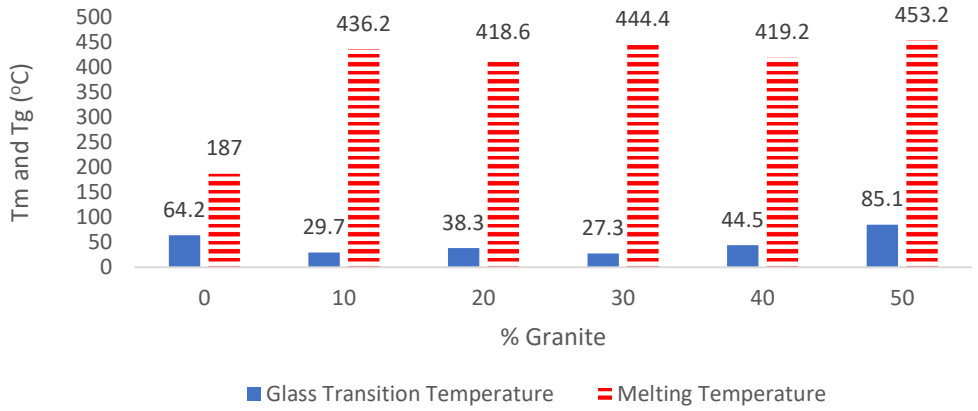


Figure 6: Variation of glass transition and melting temperatures for the composites

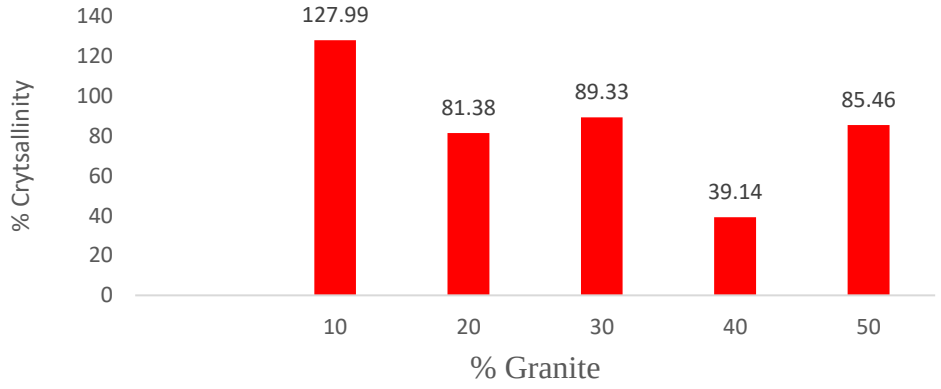


Figure 7: Variation of % crystallinity of the composite

From Figure 6 it can be seen that there is significant shift in both the glass transition (Tg) and the melting temperature (Tm) of the composite at the start of the GTP addition. Notably after fluctuations, Tg and Tm increases considerably. This indicates a trend towards greater rigidity. This phenomenon can be attributed to the introduction of more rigid and thermally stable granite particles into the polymer matrix, which constrained the polymer's amorphous structure. The presence of thermally stable granite particles delayed the polymer's melting process, resulting in a higher Tm. Material higher granite content (50% granite) results in higher Tg and Tm ($85.1^0$C and $453.2^o$C) respectively, reflecting enhanced rigidity and elevated temperature stability and therefore the best for this application.

Figure 7 shows a random variation in crystallinity from 10% to 50%, suggesting that the addition of 10% granite

reinforcement boosted the crystalline structure within the composite, possibly due to the sudden nucleating effect of the GTP. Conversely, at 40%, there is a sharp drop in crystallinity, indicating that this amount significantly disrupted the polymer's crystalline structure, potentially due to an excessive amount of granite, which might hinder the polymer's ability to crystallize effectively. However, in a study conducted (Galo *et al.,* 2019) observed that crystallinity does not change after thermocycling treatment of some polymers (polyethylene and Polyethylene terephthalate).

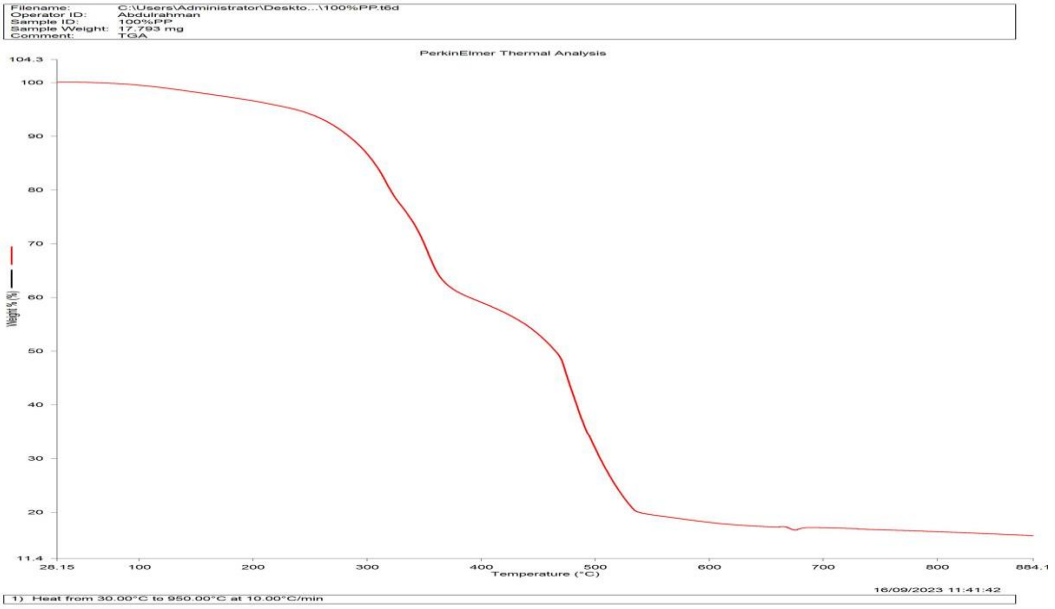


Figure 8: TGA curve of neat PP

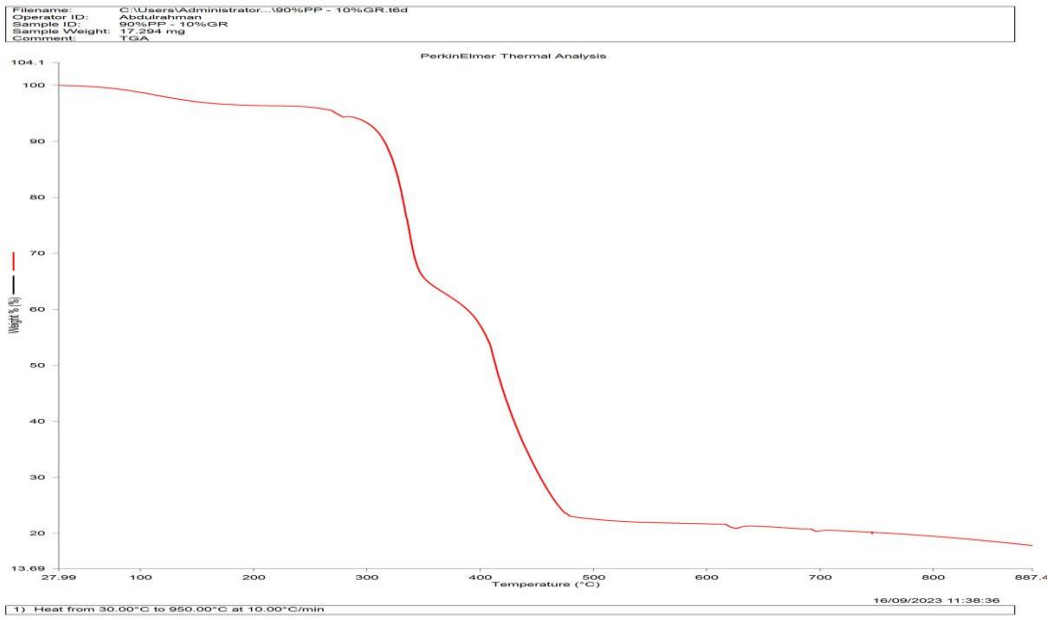


Figure 9: TGA curve of PP/10% GTP

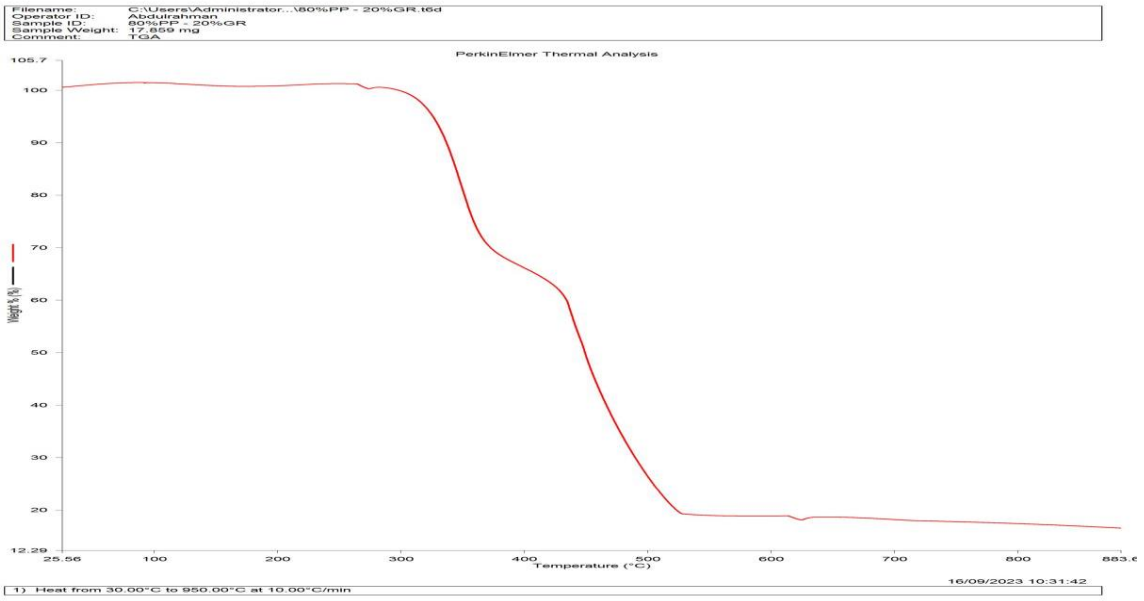


Figure 10: TGA curve of PP/20 wt% GTP

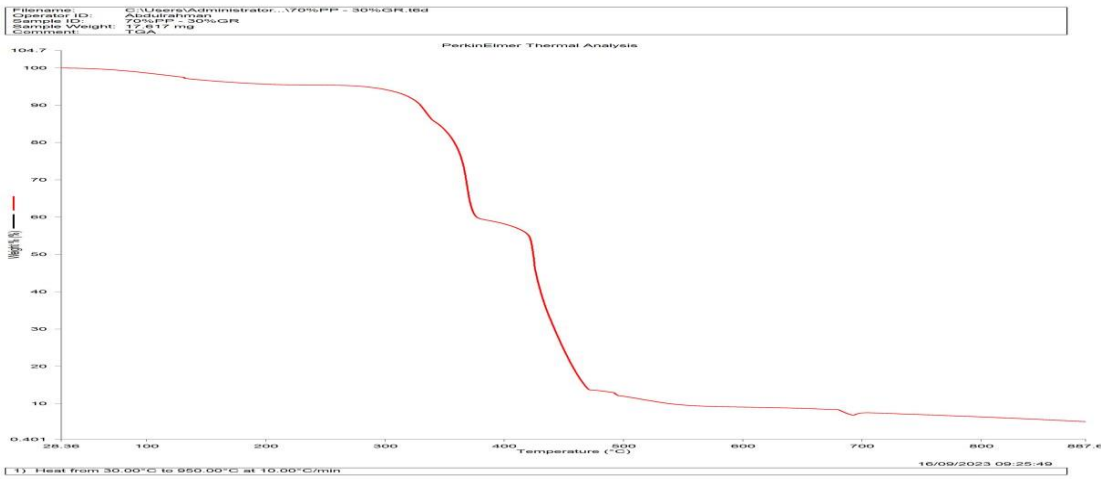


Figure 11: TGA curve of PP/30 wt% GTP

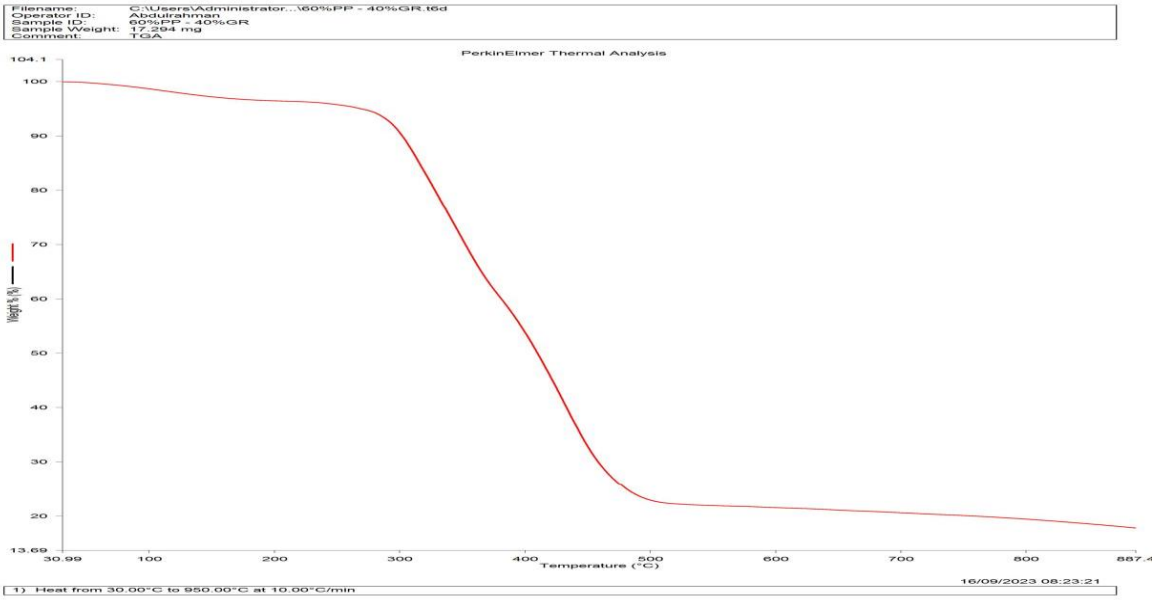


Figure 12: TGA curve of PP/40 wt% GTP

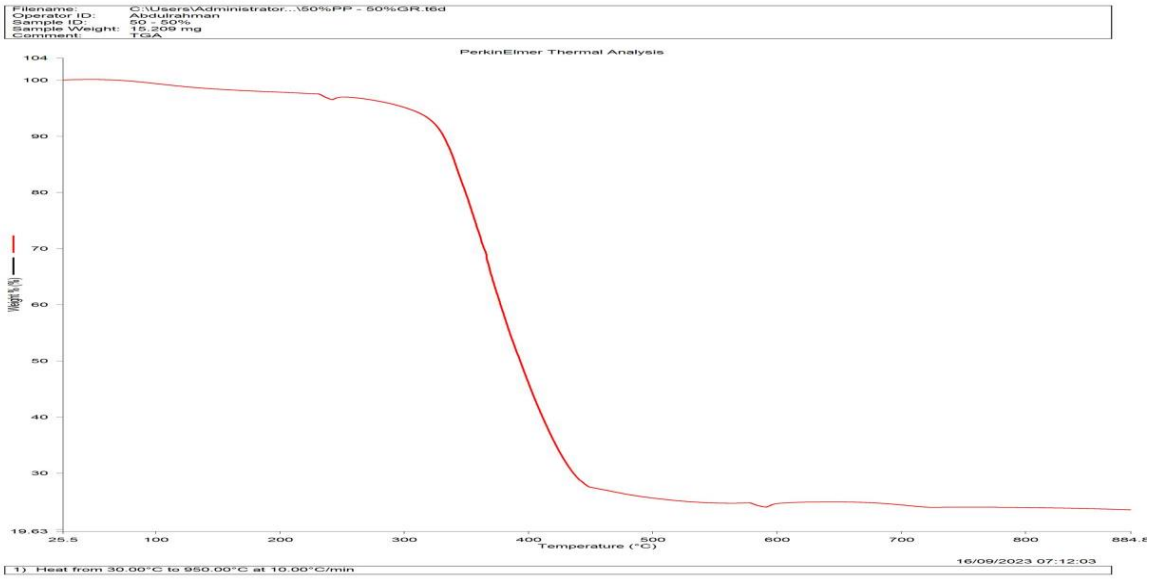


Figure 13: TGA curve of PP/50 wt% GTP

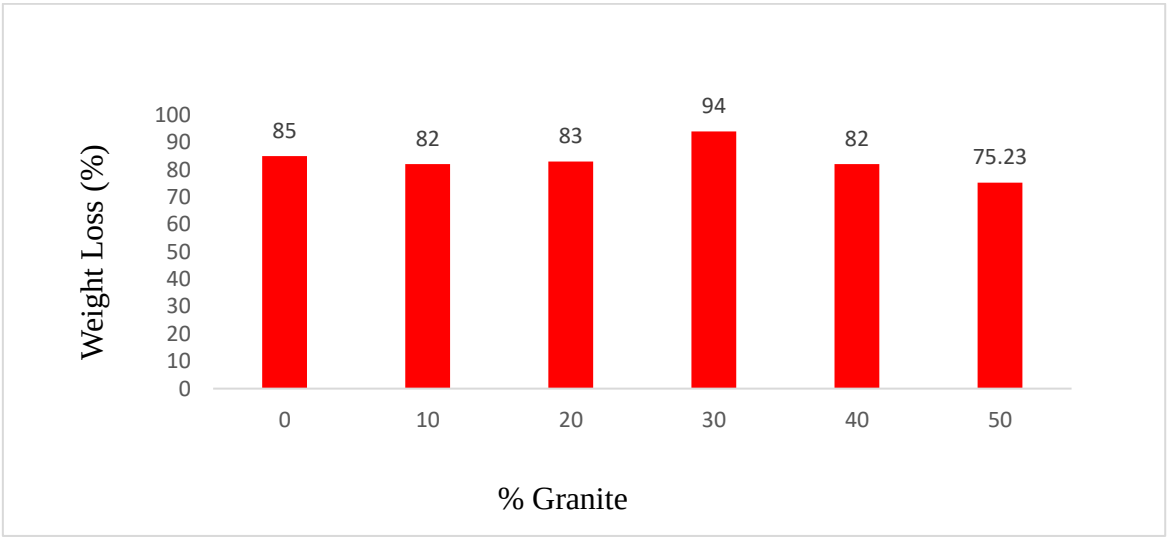


Figure 14: Weight loss in respect to temperature changes with GTP obtained from thermogravimetric analysis.

Figures 8-14 display TGA results which clearly demonstrate a correlation between the weight percentage of GTP and the percentage weight loss of the composite. Specifically, (Figure 14), at 0% granite reinforcement, the composite exhibited a weight loss of 85%, while at 30% granite, the weight loss dramatically increased to 94%. However, PP/50 wt. % GTP composite resist the thermal degradation to 75.23%. Thus, 50 wt. % GTP proportion suggests better thermal stability and less susceptibility to degradation. This composition could be particularly suitable for dental applications where dimensional stability over time is essential.

## CONCLUSION

From the density result obtained, 40 and 50 %wt PP/GTP composites display density values of about 1.173 and 1.27 g/cm$^3$ respectively which is close to the average density of human teeth of 2.84 g/cm$^3$. Further, at 50% addition, 85.2 % significant rise on thermal conductivity noticed compared to that of neat PP. On the other hand, the specific heat capacity of the composites decreased mildly with proportion of granite; this is an advantageous for dental applications. Similarly, the addition of granite filler enhances the thermal diffusivity of the composites. Again, both glass transition (Tg) and the melting temperature (Tm) of the composites increases considerably after notable fluctuations. 50 %wt PP/GTP composite crystallized effectively with crystallinity of 85.46%. In similar manner, from the thermogravimetric analysis highest thermal stability is achieved with 50 wt% GTP loading. Interestingly, dental prosthetics and restorations should be of an appropriate combination of physical properties to ensure patient comfort and overall durability. It's of significant importance to know that dental materials need to maintain a striking balance among the physical properties. Therefore, based on the outcome of the investigation, the PP/GTP composite with 50% granite particulate; represents a promising candidate for dental applications.

## ACKNOWLEDGMENTS

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