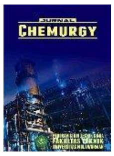
JURNAL CHEMURGY

E-ISSN 2620-7435

Available online at http://e-journals.unmul.ac.id/index.php/TK



SINTA Accreditation
No. 152/E/KPT/2023

PENGEMBANGAN GREEN POLYMER: PENGARUH PENAMBAHAN BENTONIT TERMODIFIKASI CTAB TERHADAP SIFAT TERMAL DAN KETANGGUHAN IMPAK

DEVELOPMENT OF GREEN POLYMER: EFFECT OF CTAB-MODIFIED BENTONITE ADDITION ON THE THERMAL PROPERTIES AND IMPACT TOUGHNESS

Teguh Budi Santoso[1]*, Shaila Iffani Fatiha Sari[1]

[1]Department of Polymeric Chemical Engineering, Politeknik STMI Jakarta
Jl. Letjen Suprapto No. 26 Cempaka Putih Jakarta Pusat, DKI Jakarta, Indonesia

*email : teguh@stmi.ac.id

(Received: 2025 10, 16; Reviewed: 2025 10, 21; Accepted: 2025 12, 18)

Abstrak

Konsep *green polymer* semakin mendapat perhatian karena kemampuannya mengurangi dampak lingkungan melalui pemanfaatan material daur ulang dan pengisi alami. Penelitian ini bertujuan untuk mengevaluasi pengaruh penambahan bentonit termodifikasi *Cetyl Trimethyl Ammonium Bromide* (CTAB) terhadap sifat termal dan ketangguhan impak komposit berbasis polipropilena daur ulang (rPP). Komposit disiapkan dengan variasi pengisi 0%, 3%, dan 5% berat bentonit termodifikasi CTAB. Uji termal dilakukan menggunakan *Differential Scanning Calorimetry* (DSC), sedangkan ketangguhan impak diuji menggunakan metode *Charpy*. Hasil menunjukkan bahwa penambahan 5% bentonit CTAB meningkatkan suhu leleh (Tm) hingga 165,9 °C, sedangkan komposisi 3% menghasilkan ketangguhan impak tertinggi sebesar 17,65 kJ/m². Derajat kristalinitas tertinggi (51,23%) diperoleh pada sampel tanpa pengisi. Dengan demikian, penambahan bentonit termodifikasi CTAB tidak hanya memperbaiki performa termal dan mekanik PP daur ulang, tetapi juga mendukung pengembangan *green polymer* yang ramah lingkungan.

Kata Kunci: *green polymer*, polipropilena daur ulang, bentonit termodifikasi CTAB, sifat termal, ketangguhan impak

Abstract

The concept of green polymer has gained increasing attention due to its potential to reduce environmental impacts through the use of recycled materials and natural fillers. This study investigates how the addition of Cetyl Trimethyl Ammonium Bromide (CTAB)-modified bentonite influences the thermal behavior and impact toughness of recycled polypropylene (rPP) composites. The composites were prepared with 0 wt%, 3 wt%, and 5 wt% CTAB-modified bentonite. Thermal analysis was performed using Differential Scanning Calorimetry (DSC), while impact toughness was determined using the Charpy method. The results showed that 5 wt% CTAB-modified bentonite increased the melting temperature (Tm) to 165.9 °C, whereas 3 wt% yielded the highest impact toughness of 17.65 kJ/m². The highest crystallinity (51.23%) was obtained in the sample without

JURNAL CHEMURGY

E-ISSN 2620-7435

Available online at http://e-journals.unmul.ac.id/index.php/TK

SINTA Accreditation
No. 152/E/KPT/2023

filler. Therefore, the incorporation of CTAB-modified bentonite not only enhances the thermal and mechanical performance of recycled PP but also promotes the development of environmentally friendly green polymers.

***Keywords**: green polymer, recycled polypropylene, CTAB-modified bentonite, thermal properties, impact toughness*

1. INTRODUCTION

Plastics play an essential role in modern life, with steadily increasing production driven by their versatility and lightweight characteristics. In the automotive sector, plastics are commonly used as composite materials due to their low density, chemical resistance, and favorable mechanical properties (Aryanti, 2021). Among various thermoplastics, polypropylene (PP) is one of the most widely applied materials, offering an excellent balance of mechanical strength, chemical resistance, and processability (Maddah, 2016).

As environmental awareness continues to rise, the green polymer concept has emerged as a crucial approach in sustainable materials engineering. Green polymers are sustainable polymeric materials developed through recycling, the use of natural fillers, and environmentally friendly processing (Wypych, 2016). Utilizing recycled polypropylene (rPP) as a composite matrix not only aligns with this concept but also contributes to waste reduction and cost efficiency (Budiyantoro et al., 2019).

However, recycled PP typically exhibits reduced mechanical and thermal properties due to chain scission during reprocessing (Bouakkaz et al., 2018). Reinforcement with natural fillers such as bentonite, which is rich in montmorillonite, can improve stiffness and thermal stability (Bukit et al., 2013; Sirait, 2018). Nevertheless, the hydrophilic nature of bentonite leads to poor compatibility with hydrophobic PP. To overcome this issue, bentonite can be modified with a cationic surfactant such as CTAB to form organobentonite, which enhances filler dispersion and interfacial adhesion (Ismail & Mathialagan, 2012).

Previous studies have shown that CTAB-modified bentonite improves the thermal and mechanical properties of polymer composites (Arora et al., 2011). Therefore, this study aims to evaluate the effect of CTAB-modified bentonite addition on the thermal behavior and impact toughness of rPP composites as part of the green polymer initiative for sustainable automotive materials.

2. RESEARCH METHODOLOGY

2.1 Materials and Equipment

Recycled polypropylene (rPP) was used as the polymer matrix, while bentonite served as the filler. The modifier Cetyl Trimethyl Ammonium Bromide (CTAB, 0.1 M solution) was employed to prepare organobentonite. Distilled water was used for washing. The main equipment included a twin-screw compounder (Teach Line ZK 25×24 D), pelletizer, manual forming machine (Cometech QC 601-A), granulator, oven dryer, DSC 214 Polyma, and ZwickRoell Charpy impact tester.

2.2 Preparation of CTAB-Modified Bentonite

Bentonite was dispersed in distilled water and treated with 0.1 M CTAB at 50 °C for 2 h to promote cation exchange and surfactant intercalation within the clay layers. The suspension was filtered, washed until the filtrate reached neutral pH, and dried at 80 °C to a constant weight. The dried product was sieved through a 200-mesh screen to obtain uniform particle size.

2.3 Composite Preparation

The rPP was dried at 80 °C to remove residual moisture. Composites were prepared by melt-compounding rPP with 0 wt%, 3 wt%, and 5 wt% CTAB-modified bentonite using a twin-screw extruder at 190 °C and 60 rpm. The extrudate was pelletized, granulated, and compression-molded into 4 mm-thick sheets using a manual forming machine at 190 °C with sequential pressures of 100, 200, and 300 kgf/cm² over 20 minutes.

Figure 1. Recycled polypropylene (rPP) composites containing 0%, 3%, and 5% CTAB-modified bentonite after molding

2.4 Characterization

Thermal analysis was performed using Differential Scanning Calorimetry (DSC) according to ASTM D3418. Approximately 5–10 mg of each sample was heated from −20 °C to 200 °C at 10 °C/min. The melting temperature (Tm) and enthalpy of fusion (ΔHm) were recorded, and the degree of crystallinity (Xc) was calculated using:

$$X_c = \frac{\Delta H_m}{\Delta H_m^0 \times w_{PP}} \times 100\% \quad (1)$$

where $\Delta H_m^0 = 209\, J/g$ represents the enthalpy of fusion for 100% crystalline PP.

Impact toughness was measured using a ZwickRoell Charpy tester in accordance with ISO 179 at room temperature (21 °C) with a 5 J pendulum. The reported values represent the average and standard deviation of ten specimens for each composition.

3. RESULT AND DISCUSSION

3.1 Effect of CTAB-Modified Bentonite on Melting Temperature

The effect of CTAB-modified bentonite addition on the melting temperature (Tm) and crystallinity (Xc) of recycled polypropylene (rPP) composites was analyzed using Differential Scanning Calorimetry (DSC). The thermograms presented in Figures 2–4 illustrate the endothermic peaks corresponding to the melting transitions of rPP and its composites containing 3 wt% and 5 wt% CTAB-modified bentonite. The numerical values obtained from the DSC analysis are summarized in Table 1.

At 0 wt% bentonite (Figure 2), neat rPP exhibited a single melting endotherm with a peak temperature of 165.3 °C, which is typical for isotactic polypropylene. When 3 wt% CTAB-modified bentonite was incorporated (Figure 3), the melting peak slightly shifted to 165.6 °C, while the enthalpy of fusion (ΔHm) decreased from 104.8 J/g to 98.5 J/g. A further increase to 5 wt% filler (Figure 4) resulted in a melting temperature of 165.9 °C and a ΔHm of 96.22 J/g.

The slight increase in Tm with higher filler loading indicates restricted molecular chain mobility, likely due to improved interfacial interactions between rPP and organophilic bentonite. Meanwhile, the reduction in ΔHm suggests that the incorporation of CTAB-modified bentonite reduced the degree of crystallinity, as the clay platelets acted as physical barriers to regular crystal growth.

These observations confirm that surface modification of bentonite with CTAB enhanced its dispersion and compatibility within the rPP matrix. Consequently, the polymer–filler interfacial bonding became stronger, limiting chain motion during melting. This finding aligns with Zhang et al. (2012) and Benhacine et al. (2014), who reported that organophilic clays improve polymer thermal stability and alter crystallization behavior through intercalation and strong interfacial adhesion.

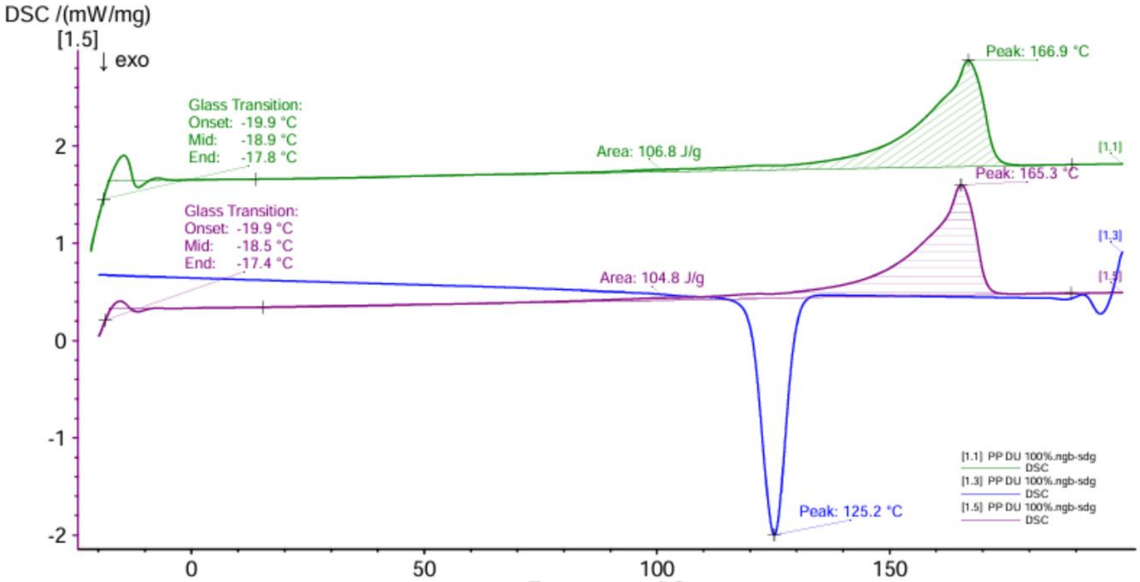


Figure 2. DSC Thermogram of rPP 100%/ Bentonite 0%

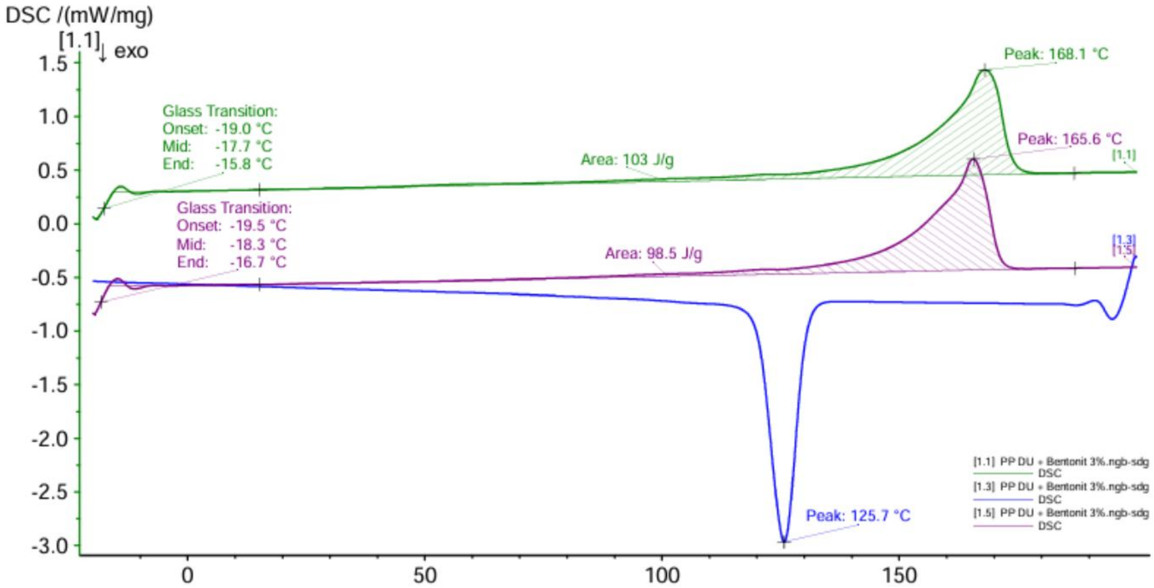


Figure 3. DSC Thermogram of rPP 97%/ Bentonite 3%

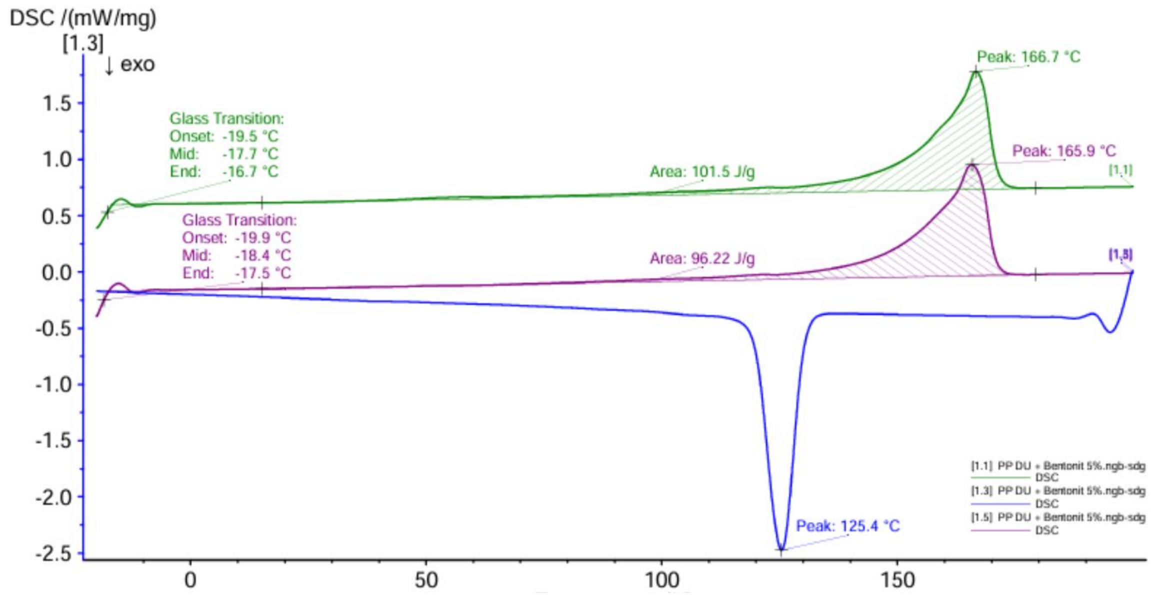


Figure 4. DSC Thermogram of rPP 95%/ Bentonite 5%

Table 1. Thermal properties of rPP/CTAB-modified bentonite composites

Composition (rPP/Bentonite CTAB)	Tm (°C)	ΔHm (J/g)	Xc (%)
100/0	165.3	104.8	50.60
97/3	165.6	98.5	47.56
95/5	165.9	96.22	46.46

3.2 Crystallinity Behavior

The degree of crystallinity (Xc) of the rPP composites decreased with increasing filler content, as presented in Table 1 and illustrated in Figure 5. Neat rPP exhibited the highest crystallinity at 50.6%, while the 3 wt% and 5 wt% CTAB-bentonite composites showed 47.56% and 46.46%, respectively.

The reduction in crystallinity indicates that the filler particles interfered with the regular packing of polymer chains, resulting in less ordered crystalline regions. Although inorganic fillers such as bentonite can act as nucleating agents (Othman et al., 2006), the surfactant layer introduced by CTAB may hinder nucleation efficiency by creating steric barriers that limit crystal growth (Mohammedi et al., 2021).

These findings agree with the report by Melyna et al. (2024), which showed that filler-induced structural imperfections can modify the melting behavior and overall crystallinity of polymer composites. The combination of slightly increased Tm and decreased Xc in this study confirms that CTAB modification enhanced polymer–filler adhesion while limiting molecular mobility.

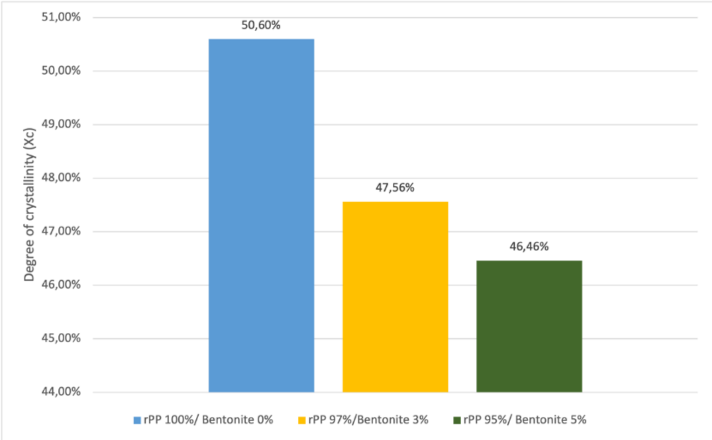


Figure 5. Degree of crystallinity (Xc) of rPP/CTAB-modified bentonite composites

3.3 Impact Toughness

The Charpy impact test results are summarized in Table 2 and Figure 6. Neat rPP exhibited the lowest impact toughness at 8.63 ± 3.97 kJ/m². The addition of 3 wt% CTAB-modified bentonite significantly enhanced toughness to 17.65 ± 4.35 kJ/m². However, further increasing the filler to 5 wt% slightly reduced toughness to 16.71 ± 4.31 kJ/m²

Table 2. Impact toughness of rPP/CTAB-modified bentonite composites

Composition (rPP/Bentonite CTAB)	Impact strength(kJ/m²)
100/0	8.63 ± 3.97
97/3	17.65 ± 4.35
95/5	16.71 ± 4.31

The improvement in toughness at 3 wt% filler loading can be attributed to the uniform dispersion of organobentonite within the rPP matrix, which promotes effective stress transfer and energy dissipation during impact. At this concentration, the filler acts as a micro-reinforcement that enhances impact resistance without compromising ductility.

In contrast, at 5 wt% filler, the slight reduction in impact toughness is likely due to agglomeration of bentonite particles, which act as stress concentrators and initiate microcracks, leading to brittle failure. This behavior is consistent with the findings of Chen and Evans (2009) and Sreekanth et al. (2009), who reported that excessive filler content in polymer composites can reduce toughness due to particle clustering and limited matrix deformability.

Overall, the results demonstrate that a 3 wt% loading of CTAB-modified bentonite provides the most balanced mechanical performance, achieving a significant improvement in impact toughness while maintaining good thermal stability.

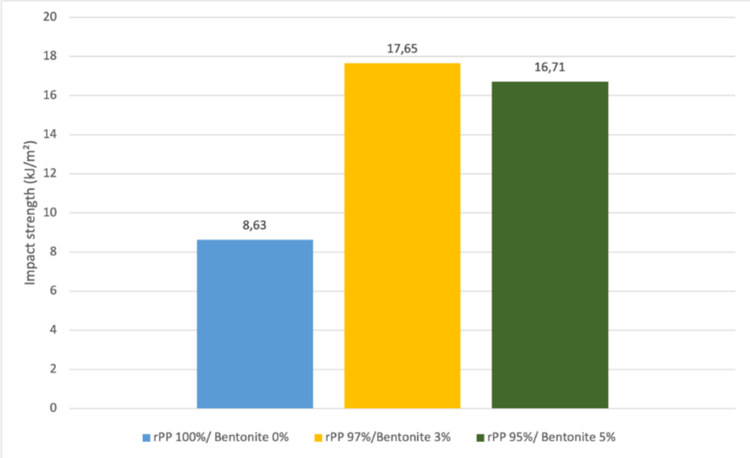


Figure 6. Impact toughness of rPP/CTAB-modified bentonite composites

4. CONCLUSION

The incorporation of CTAB-modified bentonite into recycled polypropylene (rPP) composites successfully enhanced both thermal and mechanical performance. The melting temperature increased slightly from 165.3 °C to 165.9 °C, while the highest impact toughness (17.65 kJ/m²) was achieved at 3 wt% filler. Crystallinity decreased with higher filler content, indicating limited polymer chain mobility due to improved filler–matrix interactions.

In summary, a 3 wt% loading of CTAB-modified bentonite provided the most balanced improvement, demonstrating the material's potential as a sustainable filler for green polymer composites based on recycled PP. These results highlight its suitability for lightweight and environmentally friendly automotive components.

REFERENCES

Arora, A., Choudhary, V. and Sharma, D.K. (2011) 'Effect of clay content and clay/surfactant on the mechanical, thermal and barrier properties of polystyrene/organoclay nanocomposites', *Journal of Polymer Research*, 18(4), pp. 843–857. https://doi.org/10.1007/s10965-010-9481-6

Aryanti, F.I. (2021) 'Pembuatan komposit polimer polipropilena/talk/masterbatch hitam pada cover tail', *Jurnal Teknologi dan Manajemen*, 19(1), pp. 1–6. https://doi.org/10.52330/jtm.v19i1.8

Benhacine, F., Yahiaoui, F. and Hadj-Hamou, A.S. (2014) 'Thermal stability and kinetic study of isotactic polypropylene/Algerian bentonite nanocomposites prepared via melt blending', *Journal of Polymers*, 2014, pp. 1–9. https://doi.org/10.1155/2014/426470

Bouakkaz, A.O., Albedah, A., Bouiadjra, B.B., Khan, S.M.A., Benyahia, F. and Elmeguenni, M. (2018) 'Effect of temperature on the mechanical properties of polypropylene–talc composites', *Journal of Thermoplastic Composite Materials*, 31(7), pp. 896–912. https://doi.org/10.1177/0892705717729016

Budiyantoro, C., Sosiati, H., Nugroho, A. and Anggariawan, A. (2019) 'Thermal characterization of mixed virgin-recycle acrylonitrile butadiene styrene', *JMPM (Jurnal Material dan Proses Manufaktur)*, 3(2), pp. 59–64. https://doi.org/10.18196/jmpm.3241

Bukit, N., Frida, E. and Harahap, M.H. (2013) 'Preparation natural bentonite in nanoparticle material as filler nanocomposite high density polyethylene (HDPE)', *Chemistry and Materials Research*, 3(13), pp. 10–15.

Chen, B. and Evans, J.R.G. (2009) 'Impact strength of polymer-clay nanocomposites', *Soft Matter*, 5(19), pp. 3572–3584. https://doi.org/10.1039/b902073j

Ismail, H. and Mathialagan, M. (2012) 'Comparative study on the effect of partial replacement of silica or calcium carbonate by bentonite on the properties of EPDM composites', *Polymer Testing*, 31(2), pp. 199–208. https://doi.org/10.1016/j.polymertesting.2011.09.002

Maddah, H.A. (2016) 'Polypropylene as a promising plastic: A review', *American Journal of Polymer Science*, 6(1), pp. 1–11. https://doi.org/10.5923/j.ajps.20160601.01

Melyna, E., Wulansari, I., Fauziyah, Z. and Sari, E. (2024) 'Pengaruh penambahan zinc oxide (ZnO) terhadap kuat tarik, kuat impak, dan kristalinitas komposit PP daur ulang/serat rami', *Journal of Polymer Chemical Engineering and Technology*, 2(1), pp. 19–28. https://doi.org/10.52330/jpcet.v2i1.346

Mohammedi, N., Zoukrami, F. and Haddaoui, N. (2021) 'Preparation of polypropylene/bentonite composites of enhanced thermal and mechanical properties using L-leucine and stearic acid as coupling agents', *Technology & Applied Science Research*, 11(3), pp. 7207–7216. https://doi.org/10.48084/etasr.4148

Othman, N., Ismail, H. and Mariatti, M. (2006) 'Effect of compatibilisers on mechanical and thermal properties of bentonite filled polypropylene composites', *Polymer Degradation and Stability*, 91(8), pp. 1761–1774. https://doi.org/10.1016/j.polymdegradstab.2005.11.022

Sirait, M., Gea, S., Siregar, N., Bukit, N., Ginting, E.M. and Zega, R.F. (2018) 'Fabrication of poly(vinyl alcohol)/bentonite nanocomposites using sol-gel method', *Asian Journal of Chemistry*, 30(10), pp. 2210–2214. https://doi.org/10.14233/ajchem.2018.21388

Sreekanth, M.S., Bambole, V.A., Mhaske, S.T. and Mahanwar, P.A. (2009) 'Effect of particle size and concentration of fly ash on properties of polyester thermoplastic elastomer composites', *Journal of Minerals & Materials Characterization & Engineering*, 8(3), pp. 237–248. https://doi.org/10.4236/jmmce.2009.83020

Wypych, G. (2016) *Handbook of Fillers.* 4th ed. Toronto: ChemTec Publishing, pp. 13–266. https://doi.org/10.1016/B978-1-895198-91-1.50004-X

Zhang, Y.Y., Jiang, S.L., Yu, Y., Xiong, G., Zhang, Q.F. and Guang, G.Z. (2012) 'Phase transformation mechanisms and piezoelectric properties of poly(vinylidene fluoride)/montmorillonite composite', *Journal of Applied Polymer Science*, 123(5), pp. 2595–2600. https://doi.org/10.1002/app.34431