

1-1-2023

## Effect of calcium carbonate particle size and content on the thermal properties of PVC foamed layer used for coated textiles

MOUNA STAMBOULI

WALID CHAOUCH

SONDES GARGOUBI

RIADH ZOUARI

SLAH MSAHLI

Follow this and additional works at: <https://journals.tubitak.gov.tr/chem>

 Part of the [Chemistry Commons](#)

### Recommended Citation

STAMBOULI, MOUNA; CHAOUCH, WALID; GARGOUBI, SONDES; ZOUARI, RIADH; and MSAHLI, SLAH (2023) "Effect of calcium carbonate particle size and content on the thermal properties of PVC foamed layer used for coated textiles," *Turkish Journal of Chemistry*. Vol. 47: No. 1, Article 5. <https://doi.org/10.55730/1300-0527.3514>

Available at: <https://journals.tubitak.gov.tr/chem/vol47/iss1/5>

This Article is brought to you for free and open access by TÜBİTAK Academic Journals. It has been accepted for inclusion in Turkish Journal of Chemistry by an authorized editor of TÜBİTAK Academic Journals. For more information, please contact [academic.publications@tubitak.gov.tr](mailto:academic.publications@tubitak.gov.tr).

## Effect of calcium carbonate particle size and content on the thermal properties of PVC foamed layer used for coated textiles

Mouna STAMBOULI\* , Walid CHAOUCH, Sondes GARGOUBI, Riadh ZOUARI, Slah MSAHLI

Textile Engineering Laboratory, LGTex, ISET Ksar Hellal, University of Monastir, Monastir, Tunisia

Received: 30.05.2022 • Accepted/Published Online: 22.11.2022 • Final Version: 20.02.2023

**Abstract:** The goal of this research is to see how the amount and particle size of calcium carbonate ( $\text{CaCO}_3$ ) used in the foamed layer in use for PVC-coated textiles affects the thermal properties of the material. Two different particle sizes were used at various concentrations. The impact of different  $\text{CaCO}_3$  loadings and particle sizes on the PVC foamed layer's thermal properties were examined. Thermogravimetry (TGA and DTG) and differential scanning calorimetry (DSC) measurements were utilized to investigate the thermal properties of the PVC foamed layer and the samples have been also characterized by FTIR spectroscopy. According to the findings, the thermal stability of the foamed layer was improved with the addition of calcium carbonate. Through the higher surface area between the filler and the PVC matrix, smaller particle sizes have produced the best results. The PVC foamed layer shows also changes in FTIR spectra after adding  $\text{CaCO}_3$ , and the intensity of peaks increases with decreasing  $\text{CaCO}_3$  particle size.

**Key words:** Synthetic leather, filler, thermal stability

### 1. Introduction

Synthetic leather, also called artificial leather or coated textile, is becoming more popular as a substitute for natural leather in a variety of applications thanks to its low cost and its similar look and durability to authentic leather. The coating is increasingly becoming an important way of adding value to textiles. It aims to develop the functional properties of textiles, improve certain characteristics, and guarantee that fabrics meet parameters of performance that will not be achievable from uncoated and leathered fabrics [1].

Polyvinyl chloride (PVC) is one of the most extensively utilized polymers in the coating industry due to its low cost, low density, fire retardancy, excellent insulation, and high mechanical and thermal properties. PVC synthetic leather is widely used in daily life [2–4].

So far, the significance of their properties has been greatly emphasized as a result of their application in various domains such as footwear, automotive, flooring and wall coverings, handbag accessories, medical equipment, and clothing [5,6]. The superficial layer, foamed layer (internal layer), and backing textile are common components of these materials [7].

Their basic components are as follows: PVC resin, a stabilizer, a plasticizer, a blowing agent, and a filler [8]. Plastisol is made by evenly mixing these components [9,10]. Fillers are especially utilized to reduce the cost of the final product. Nevertheless, their properties are a critical factor in defining several technical features of PVC synthetic leather [11–13].

Calcium carbonate is one of the most widely used fillers for the PVC leather industry [14–16], conventionally  $\text{CaCO}_3$  has been employed to minimize its cost and enhance its melting viscosity, and mildly increase the modulus of the final product due to its small surface area and undesirable geometrical aspects [17]. However, some mechanical properties remained constant or, in some circumstances, declined [18]. Particle shape and size and filler quantity have recently been reported to have a significant effect on PVC materials filled with calcium carbonate [19]. Rigorous studies have shown the effect of calcium carbonate on the mechanical behavior of PVC materials [20].

Other studies have shown that  $\text{CaCO}_3$  particle size and content have a significant effect on the morphological structure [17,21,22], the thermal characteristics [16,23,30], and the physical properties of the PVC products [17,21].

However, no published references on the subject of the foamed layer used for PVC synthetic leather have been found.

This study aims to explore the functionality of calcium carbonate in the thermal property enhancement of the PVC

\* Correspondence: Mounastambouli@gmail.com

foamed layer used for coated textiles and to provide a detailed analysis to demonstrate the impact of  $\text{CaCO}_3$  concentration and particle size on the thermal characteristics of the PVC synthetic leather foamed layer.

## 2. Experimental

### 2.1. Raw materials

PVC resin, Plasticizer (DINP), stabilizer,  $\text{CaCO}_3$  fillers, blowing agent (azodicarbonamide), kicker, transfer paper, pigment, and textile fabric were generously donated by PLASTISS company (Monastir, Tunisia). The different calcium carbonate particle sizes (1.8  $\mu\text{m}$  and 0.9  $\mu\text{m}$ ) were provided by SOFAP company (Sfax-Tunisia).

### 2.2. Synthesis of PVC foamed layer

In this study, PVC foamed layers have been developed from PVC plastisol. To make PVC plastisol, 100 parts PVC resin, 80 parts DINP, 4 parts azodicarbonamide, 2 parts Kicker, and 1.5 parts stabilizers were mixed in a mechanical stirrer. Then 25%, 50%, 75%, 100%, or 125% (by weight) of fillers were included and mixed until a consistent mixture was obtained.

The transfer coating technique has been used to create a PVC-foamed layer. The plastisol is applied to the transfer paper with a blade and the thickness is controlled simultaneously. The resultant film, called the foamed layer or internal layer, once it is dried at 200 °C for 80 s and steamed. During plasticizing, the azodicarbonamide (chemical blowing agent) decomposes, generating ammonia gas ( $\text{NH}_3$ ), which dissipates in the plastisol. Until curing is completed, the gas must remain dissolved in the melting.

### 2.3. Thermal characterization

The TGA and DTG curves of the foamed layers have been analyzed using Perkin Elmer STA 6000 in the temperature range of 0–600 °C at a heating rate of 10 °C  $\text{min}^{-1}$  under a nitrogen stream and an oxidizing atmosphere.

DSC measurements were carried out at a heating rate of 0.1 °C/min in ambient air conditions, using a Mettler Toledo.

### 2.4. Chemical characterization

The FTIR spectra have been acquired on a Perkin-Elmer BxFTIR system spectrometer (by dispersing samples in KBr disks).

## 3. Results and discussion

### 3.1. FTIR characterization

The FTIR spectra of PVC resin, represented in Figure 1a, show the characteristic vibrational modes as summarized in Table 1 [31].

Figure 1b shows the FTIR spectra of calcium carbonate ( $\text{CaCO}_3$ ), which is characterized by the three C-O elongation modes of the carbonate groups [32]. They appear as a triplet consisting of:

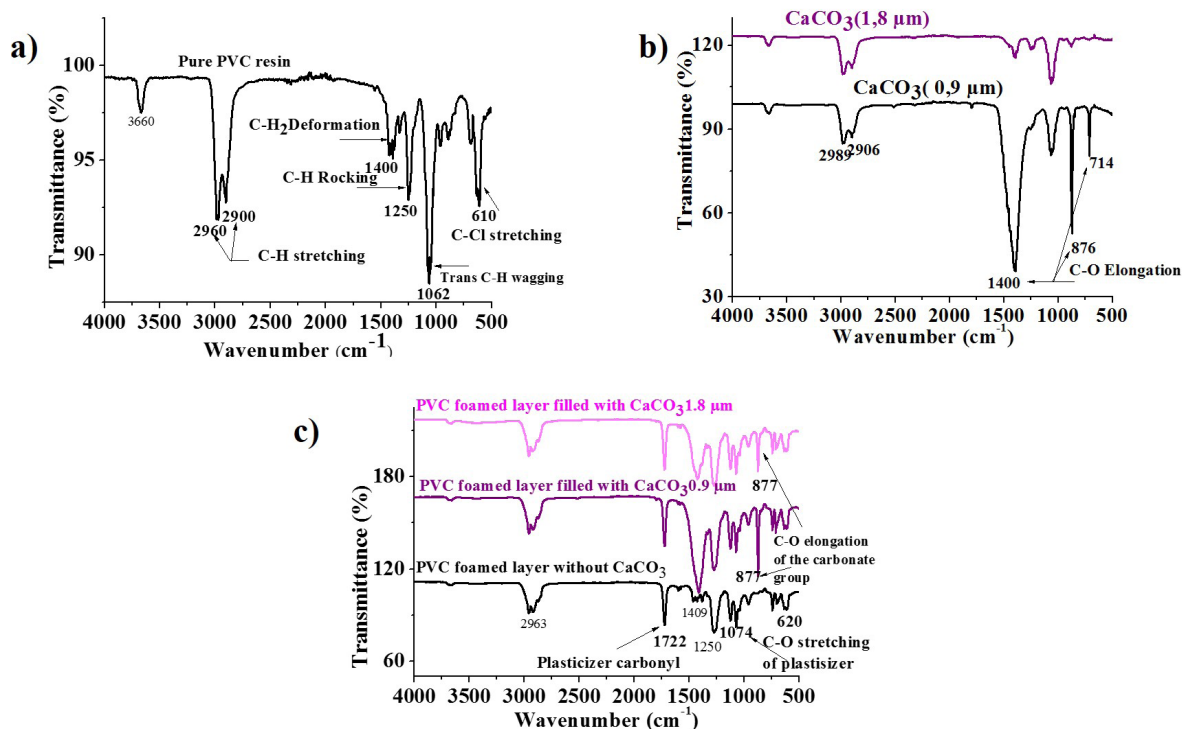
- A large and intense absorption band at 1400  $\text{cm}^{-1}$ .
- A thin and intense band at 876  $\text{cm}^{-1}$ .
- A thin and weak band at 714  $\text{cm}^{-1}$ .

These similar absorption bands were also reported by Wen et al. [33] and Luo et al. [34].

The FTIR spectra of the PVC internal layer with 0% and 50% of  $\text{CaCO}_3$  with different particle sizes (0.9  $\mu\text{m}$  and 1.8  $\mu\text{m}$ ) are shown in Figure 1c. The different samples were characterized by different types of elongation modes [35] which appear as several absorption bands and are as follows: the peak set at 2963  $\text{cm}^{-1}$  corresponds to the C-H stretch bond [36], the peak located around 1409  $\text{cm}^{-1}$  suitable for the C-H aliphatic bending bond, the peak located at 1250  $\text{cm}^{-1}$  is attributed to the C-H deformation bond near chlorine (Cl), the peak observed in the 1000–1100  $\text{cm}^{-1}$  region corresponds to the PVC backbone chain's C-C stretch bond. Finally, the peak detected at 620  $\text{cm}^{-1}$  represents C-Cl gauche bonds, similar absorption bands have been reported by Atef et al. [37], Lee et al. [38], and Ramesh et al. [36].

**Table 1.** Vibrational modes observed in PVC resin.

Modes of vibration	Wavenumber ( $\text{cm}^{-1}$ )
-CH stretching	2900–2960
-CH <sub>2</sub> deformation	1400
CH rocking	1250
trans CH wagging	1062
C-Cl stretching	610



**Figure 1.** FTIR spectra. a. Pure PVC resin; b. Calcium carbonate with various particle sizes; c. PVC internal layer before and after adding CaCO<sub>3</sub> with different particle sizes.

The CH<sub>2</sub> bending peak, with a wavenumber of approximately 1409 cm<sup>-1</sup>, is maximum in the reinforced samples, and the peak intensity increases with decreasing particle size, compared to the FTIR spectra of the reinforced foamed layer with the pure samples as a reference. Another notable difference is the presence of a very thin and sharp peak in the reinforced samples with a wavenumber of around 877 cm<sup>-1</sup>, which can be attributed to the C-O elongation modes of the carbonate groups [39].

### 3.2. Thermal characterization

Figure 2 shows that the fusion point of the pure PVC foamed layer was detected at 290.39 °C [42]. DSC curves of PVC/50% CaCO<sub>3</sub> foamed layers with a fine particle diameter (0.9 μm) and PVC/50% CaCO<sub>3</sub> with a large particle diameter (1.8 μm) have revealed a linked melting peak located around 304.71 °C and 296.36 °C, respectively. It is clear that by adding CaCO<sub>3</sub>, the fusion point of the pure PVC foamed layer was raised to a higher temperature. It can be concluded that calcium carbonate improves the thermal stability of the PVC foamed layer.

Etienne et al. [24], Matthews et al. [27], Tuen et al. [43], Zhu et al. [30], and Sun et al. [28] confirmed these findings and attributed them to the CaCO<sub>3</sub>'s HCl scavenger action during PVC thermal decomposition.

As shown in Figure 2, it has also been demonstrated that thermal stability is improved when using small particle sizes of CaCO<sub>3</sub> due to their larger surface area, as previously reported by Liu et al. [26]. Calcium carbonate particles with a larger surface area have absorbed the HCl gas released during the PVC thermal decomposition more successfully.

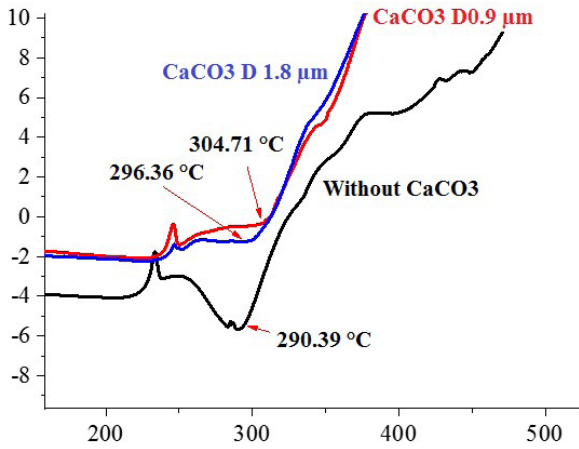
Figures 3 and 4 illustrate the TGA weight loss and derivative thermograms (DTG), respectively, for pure PVC and PVC/50% CaCO<sub>3</sub> foamed layers with varying CaCO<sub>3</sub> particle sizes. Thermal factors are listed in Table 2.

From the TGA and DTG curves illustrated in Figures 3 and 4, the thermal degradation of pure PVC and PVC/CaCO<sub>3</sub> foamed layers happens in two main stages, and two substantial weight losses can be seen [24,39].

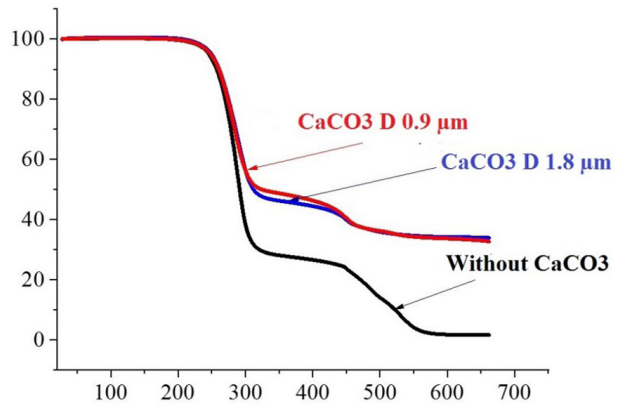
As also observed by Etienne et al. [24], a minor delay in the two onset decomposition temperatures was noticed (Figure 3) and increased with the use of small CaCO<sub>3</sub> particle size.

Moreover, the weight loss of the PVC/50% CaCO<sub>3</sub> foamed layer was lower than the pure PVC foamed layer, and the internal layer filled with small particles typically has the lowest weight loss among the other samples used in this study.

We can conclude that the incorporation of CaCO<sub>3</sub> can ameliorate the thermal stability of the PVC foamed layer used for PVC synthetic leather, and using a small CaCO<sub>3</sub> particle size increases the enhancement of the thermal stability. The results of the TGA and DTG analyses were in good agreement with the DSC data.



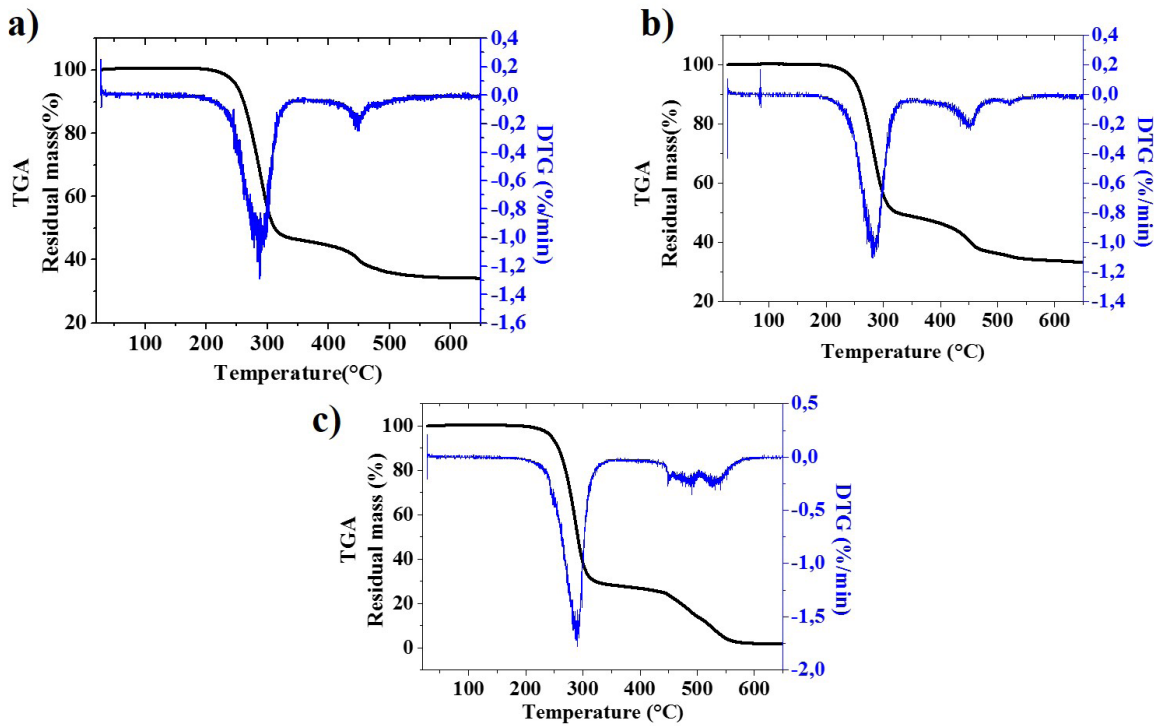
**Figure 2.** DSC curves of the pure PVC and PVC/50% CaCO<sub>3</sub> foamed layers prepared with different particle sizes (0.9 μm and 1.8 μm).



**Figure 3.** TGA curves of pure PVC and PVC/50% CaCO<sub>3</sub> foamed layer with different particle sizes (0.9 μm and 1.8 μm).

**Table 2.** Thermal factors.

Samples	1 <sup>st</sup> decomposition		2 <sup>nd</sup> decomposition	
	T (°C)	Weight loss (%)	T (°C)	Weight loss (%)
Pure PVC	196	72	420	24
PVC/50% CaCO <sub>3</sub> (1.8 μm)	225	54	421	6.8
PVC/50% CaCO <sub>3</sub> (0.9 μm)	226	51	423	6.59



**Figure 4.** DTG curves. a. PVC/50% CaCO<sub>3</sub> (0.9 μm); b. PVC/50% CaCO<sub>3</sub> (1.8 μm); c. pure PVC foamed layer.

#### 4. Conclusion

The effects of particle size and content of  $\text{CaCO}_3$  filler on the thermal properties of the PVC foamed layer used for synthetic leather were investigated, and we have demonstrated that adding  $\text{CaCO}_3$  can ameliorate the thermal stability of the PVC foamed layer. Therefore, the melting point and the onset decomposition temperatures of the filled foamed layer increase compared with the unfilled one. Many authors attributed these findings to  $\text{CaCO}_3$ 's superior ability to trap HCl gas produced during PVC decomposition. Moreover, we observed that the most important positive impact on thermal stability was detected when using a smaller particle size, which has contributed to its larger surface area that can help to consume much more HCl gases, according to several researchers.

#### Acknowledgments

The authors would like to express their deepest gratitude to Plastiss Company and especially to Mr. Aweb Baccar for their participation and technical support.

The authors would like to thank the USCR Environmental Scanning Electron microscopy FEI Q250 Thermo Fisher, the University of Monastir for helpful technical assistance with equipment facilities.

This project is carried out under the MOBIDOC (mobilization of PhDs for the realization of collaborative research work in the socio-economic environment), the scheme funded by the EU through the EMORI program and managed by the ANPR.

#### Important note

This paper has been presented at the 10<sup>th</sup> ULPAS held on 13–14 May 2022 at İstanbul Technical University-İstanbul Turkey.

#### References

1. Chiba T, Kuroda S, Yamaguchi M. Modeling the relationship between tactile sensation and physical properties of synthetic leather. *Journal of Industrial Textiles* 2020; 50 (3 ): 346-363. <https://doi.org/10.1177/1528083719830141>
2. Kang G, Seo HJ, Yun MJ, Choi DS, Ha YT et al. Method for removing odor of artificial leather and artificial leather manufactured using the same. *Google Patents* 2017.
3. Khan MZ, Baheti V, Militky J, Wiener J, Ali A et al. Self-cleaning properties of polyester fabrics coated with flower-like  $\text{TiO}_2$  particles and trimethoxy (octadecyl) silane. *Journal of Industrial Textiles* 2020; 50 (4): 543-565. <https://doi.org/10.1177/1528083719836938>
4. Chelil O, Belhaneche-Bensemra N, Garcia DL, Fernandez-Garcia M, Benaniba MT. Preparation of epoxidized sunflower oil metal soap derivatives and their use as heat stabilizers for polyvinyl chloride. *Turkish Journal of Chemistry* 2019; 43 (2): 582-593. <https://doi.org/10.3906/kim-1806-31>
5. Kinge A, Landage S, Wasif A. Nonwoven for artificial leather. *International Journal of Advanced Research in Engineering and Applied Sciences* 2013; 2 (18): 18-33 I
6. Zhang Q, Sun Y, Zhang Q, Hou J, Wang P et al. Phthalate exposure in Chinese homes and its association with household consumer products. *Science of the Total Environment* 2020; 719: 136965. <https://doi.org/10.1016/j.scitotenv.2020.136965>
7. Maia I, Santos J, Abreu MJ, Miranda T, Carneiro N et al. PVC-based synthetic leather to provide more comfortable and sustainable vehicles. *Materials Science and Engineering* 2017; <https://doi.org/10.1088/1757-899X/254/12/122006>.
8. Gargoubi S, Chaouch W, Stambouli M, Bhouiri N, Boudokhane C et al. Getting rid of the unpleasant odor in new artificial leather using natural and synthetic fragrances. *Chemical Industry and Chemical Engineering Quarterly* 2019; 25 (2): 141-151. <https://doi.org/10.2298/CICEQ171230027G>
9. Ramaraj B. Mechanical and thermal properties of ABS and leather waste composites. *Journal of Applied Polymer Science* 2006; 101 (5): 3062-3066. <https://doi.org/10.1002/app.24113>
10. Dartman T, Shishoo R. Studies of adhesion mechanisms between PVC coatings and different textile substrates. *Journal of Coated Fabrics* 1993; 22 (4): 317-335. <https://doi.org/10.1177/152808379302200409>
11. Chaturvedi S, Dave PN. Role of Nanofillers in Blends, Interpenetrating Polymer Networks, and Gels of Unsaturated Polyester Resin Polymers. In: Thomas S, Hosur M, Chirayil CJ. *Unsaturated Polyester Resins*. Elsevier, 2019, pp. 173-180. <https://doi.org/10.1016/B978-0-12-816129-6.00007-7>
12. Syabanı M, Amalyana I, Indri H, Supriyatna YI. Silica from geothermal waste as reinforcing filler in artificial leather. *Key Engineering Materials* 2020; <https://doi.org/10.4028/www.scientific.net/KEM.849.78>
13. Syabanı M, Devı C, Hermiyatı I, Angkasa AD. The effect of PVC's resin K-value on the mechanical properties of the artificial leather. *Majalah Kulit, Karet, dan Plastik* 2020; 35 (2): 75-82. <https://doi.org/10.20543/mkkp.v35i2.5639>

14. Rahman GMS, Aftab H, Islam MS, Mukhlis MZB, Ali F. Enhanced physico-mechanical properties of polyester resin film using CaCO<sub>3</sub> filler. *Fibers and Polymers* 2016; 17 (1): 59-65. <https://doi.org/10.1007/s12221-016-5612-y>
15. Eun JH, Kim MS, Sung SM, Choi BK, Jang IU et al. Effect of the viscosity of polyvinyl chloride resin and weaving structures of polyester fabric on the off-axis mechanical properties of PVC coated fabric. *Journal of Industrial Textiles* 2020; 51 (2): 2897S-2920S. <https://doi.org/10.1177/1528083720980170>
16. Abou elfettouh AEMA, Haroun AAA, RABIE AGM, Ali GAM, Abdelrahim MYM. Improving the mechanical and thermal properties of chlorinated poly (vinyl chloride) by incorporating modified CaCO<sub>3</sub> nanoparticles as a filler. *Turkish Journal of Chemistry* 2019; 43 (3): 750-759. <https://doi.org/10.3906/kim-1808-51>
17. Demir H, Sipahioğlu M, Balköse D, Ülkü S. Effect of additives on flexible PVC foam formation. *Journal of Materials Processing Technology* 2008; 195 (1-3): 144-153. <https://doi.org/10.1016/j.jmatprotec.2007.04.123>
18. Croitoru C, Spirchez C, Cristea D, Lunguleasa A, Pop MA et al. Calcium carbonate and wood reinforced hybrid PVC composites. *Journal of Applied Polymer Science* 2018; 135 (22): 46317. <https://doi.org/10.1002/app.46317>
19. Zhao L, Zhang Y, Miao Y, Nie L. Controlled synthesis, characterization and application of hydrophobic calcium carbonate nanoparticles in PVC. *Powder Technology* 2016; 288: 184-190. <https://doi.org/10.1016/j.powtec.2015.11.001>
20. Wu D, Wang X, Song Y, Jin R. Nanocomposites of poly (vinyl chloride) and nanometric calcium carbonate particles: Effects of chlorinated polyethylene on mechanical properties, morphology, and rheology. *Journal of Applied Polymer Science* 2004; 92 (4): 2714-2723.
21. Azimipour B, Marchand F. Effect of calcium carbonate particle size on PVC foam. *Journal of Vinyl and Additive Technology* 2006; 12 (2): 55-57. <https://doi.org/10.1002/vnl.20069>
22. Sun S, Li C, Zhang L, Du HL, Burnell-Grayal JS. Interfacial structures and mechanical properties of PVC composites reinforced by CaCO<sub>3</sub> with different particle sizes and surface treatments. *Polymer International* 2006; 55 (2): 158-164. <https://doi.org/10.1002/pi.1932>
23. Basilia BA, Panganiban MEG, Collado AAVC, Pesigan MOD, Pade YRO. Study on the functionality of nano-precipitated calcium carbonate as filler in thermoplastics. *Journal of Solid Mechanics and Materials Engineering* 2007; 1 (4): 564-570. <https://doi.org/10.1299/jmmp.1.564>
24. Etienne S, Becker C, Ruch D, Germain A, Calberg C. Synergetic effect of poly (vinyl butyral) and calcium carbonate on thermal stability of poly (vinyl chloride) nanocomposites investigated by TG-FTIR-MS. *Journal of Thermal Analysis and Calorimetry* 2010; 100 (2): 667-677. <https://doi.org/10.1007/s10973-009-0443-3>
25. Hassan A, Akbari A, Hing NK, Ratnam CT. Mechanical and thermal properties of ABS/PVC composites: Effect of particles size and surface treatment of ground calcium carbonate. *Polymer-Plastics Technology and Engineering* 2012; 51 (5): 473-479. <https://doi.org/10.1080/03602559.2011.651242>
26. Liu P, Zhao M, Guo J. Thermal stabilities of poly (vinyl chloride)/calcium carbonate (PVC/CaCO<sub>3</sub>) composites. *Journal of Macromolecular Science Part B: Physics* 2006; 45 (6): 1135-1140. <https://doi.org/10.1080/00222340600962650>
27. Matthews G, Plemper GS. Effects of calcium carbonate fillers on the behaviour of PVC in fires. *British Polymer Journal* 1981; 13 (1): 17-21. <https://doi.org/10.1002/pi.4980130105>
28. Sun RD, Irie H, Nishikawa T, Nakajima A, Watanabe T et al. Suppressing effect of CaCO<sub>3</sub> on the dioxins emission from poly (vinyl chloride) (PVC) incineration. *Polymer Degradation and Stability* 2003; 79 (2): 253-256. [https://doi.org/10.1016/S0141-3910\(02\)00288-4](https://doi.org/10.1016/S0141-3910(02)00288-4)
29. Tuen BS, Hassan A, Aznizam AB. Thermal properties and processability of talc-and calcium carbonate-filled poly (vinyl chloride) hybrid composites. *Journal of Vinyl and Additive Technology* 2012; 18 (2): 87-94. <https://doi.org/10.1002/vnl.20312>
30. Zhu S, Zhang Y, Zhang Y, Zhang C. Effect of CaCO<sub>3</sub>/LiCO<sub>3</sub> on the HCl generation of PVC during combustion. *Polymer Testing* 2003; 22 (5): 539-543. [https://doi.org/10.1016/S0142-9418\(02\)00150-2](https://doi.org/10.1016/S0142-9418(02)00150-2)
31. Soman VV, Kelkar DS. FTIR studies of doped PMMA-PVC blend system. In: *Macromolecular Symposia*; 2009; 152-161. <https://doi.org/10.1002/masy.200950319>
32. Mansur HS, Sadahira CM, Souza AN, Mansur AA. FTIR spectroscopy characterization of poly (vinyl alcohol) hydrogel with different hydrolysis degree and chemically crosslinked with glutaraldehyde. *Materials Science and Engineering* 2008; 28 (4): 539-548. <https://doi.org/10.1016/j.msec.2007.10.088>
33. Wen K, Li Y, Amim F, Li L. Impact of bacteria and urease concentration on precipitation kinetics and crystal morphology of calcium carbonate. *Acta Geotechnica* 2020; 15 (1): 17-27. <https://doi.org/10.1007/s11440-019-00899-3>
34. Luo X, Song X, Cao Y, Songyuwei L, Bu X. Investigation of calcium carbonate synthesized by steamed ammonia liquid waste without use of additives. *RSC Advances* 2020; 10 (13): 7976-7986. <https://doi.org/10.1039/C9RA10460G>
35. Beltrán M, Garcia J, Marcilla A. Infrared spectral changes in PVC and plasticized PVC during gelation and fusion. *European Polymer Journal* 1997; 33 (4): 453-462. [https://doi.org/10.1016/S0014-3057\(96\)00213-3](https://doi.org/10.1016/S0014-3057(96)00213-3)

36. Ramesh S, Leen KH, Kumutha K, Arof AK. FTIR studies of PVC/PMMA blend based polymer electrolytes. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 2007; 66 (4-5): 1237-1242. <https://doi.org/10.1016/j.saa.2006.06.012>
37. Atef S, El-Nashar DE, Ashour AH, El-Fiki S, El-Kameesy SU, Medhat M. Effect of gamma irradiation and lead content on the physical and shielding properties of PVC/NBR polymer blends. *Polymer Bulletin* 2020; 77 (10): 5423-5438. <https://doi.org/10.1007/s00289-019-03022-4>
38. Lee LJ, Zeng C, Cao X, Han X, Shen J et al. Polymer nanocomposite foams. *Composites Science and Technology* 2005; 65 (15-16): 2344-2363. <https://doi.org/10.1016/j.compscitech.2005.06.016>
39. Khoshnoud P, Nidal AZ. Properties of rigid polyvinyl chloride foam composites reinforced with different shape fillers. *Journal of Thermoplastic Composite Materials* 2017; 30 (11): 1541-1559. <https://doi.org/10.1177/0892705716646417>
40. Patterson J. Vinyl foam: Effect of density on physical properties. *Journal of Vinyl and Additive Technology* 1998; 4 (1): 26-29. <https://doi.org/10.1002/vnl.10005>
41. Nidhal AZ, Alian AM. Density and cell morphology of rigid foam PVC-clay nanocomposites. *Polymer-Plastics Technology and Engineering* 2010; 49 (3): 237-243. <https://doi.org/10.1080/03602550903413813>
42. Mindivan F, Gökteş M. Preparation of new PVC composite using green reduced graphene oxide and its effects in thermal and mechanical properties. *Polymer Bulletin* 2020; 77 (4): 1929-1949. <https://doi.org/10.1007/s00289-019-02831-x>
43. Tuen BS, Hassan A, Abu Bakar A. Mechanical properties of talc-and (calcium carbonate)-filled poly (vinyl chloride) hybrid composites. *Journal of Vinyl and Additive Technology* 2012; 18 (2): 76-86. <https://doi.org/10.1002/vnl.20280>