



Preparation of multistage porous polymer nanocomposites and its application in architectural design

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ABSTRACT

In order to solve the problem that the toughness (impact strength) of the traditional elastomer toughening will decrease its rigidity (modulus) while improving the toughness (impact strength) of the material, the multi-porous nano-cacO₃/polymer composite and its application in building plastics were proposed. In this essay, the mechanical properties of nano-cacO₃/PVC/CPE and nano-cacO₃/PP/SBS composites are studied. The results showed that the notch impact strength increased by 15.8 % from 46.8 kJ/m² to 54.2kJ/m² when two nano-cacO₃ was added into the PP/SBS blend system, indicating that nano-cacO₃ also toughened PP to some extent.

Conclusion: Nano Ca-CO₃ has remarkable toughening effect on PVC blending system, and also has certain toughening effect on PP blending system. The profile with nano-cacO₃ added can ensure the impact performance of low temperature drop hammer, while the notched impact strength, tensile strength, elongation at break and flexural modulus of the simply supported beam are significantly improved compared with the profile without nano-cacO₃ added. The application of nano CaCO₃/PVC/CPE composites in the profile of PVC doors and Windows is studied.

1. Introduction

The rapid development of new materials shows that porosity is one of the important factors determining material properties. Porous materials are low due to their large surface area. The skeleton density and open and permanent channel structure play an irreplaceable role in many fields. As an important class of porous materials, porous Polymers are widely used in gas adsorption, water treatment, separation, heterogeneous catalysis and many other applications due to their excellent properties of porous materials and polymer materials. Pore carbon material precursors, energy storage, photoelectric materials, sensing, biomedicine and other fields have shown unprecedented research vitality, and become the current material. And chemistry and other disciplines of research hotspot.

Nanomaterials, as ultramicro materials with great pioneering, universal application and bright prospect in the new century, have been called one of the indispensable pillars of modern social and economic development, and become the forefront of the field of materials science. Just like other technologies, in the history of nanomaterials, the initial idea of nanotechnology was also predicted. In the following decades, scholars from different countries devoted themselves to the development and research of various kinds of nanomaterials, making the

excellent properties of nanomaterials stand out among many materials and become the focus of research worldwide [1]. Nano materials are composed of Nano particles, also known as ultramicro. The size of ultramicro composed of nano materials is usually no more than 100 nm. In a broad sense, nanomaterials can be called nanomaterials as long as any of the three dimensions of length, width and height have the size of nanomaterials. The materials in three dimensional dimensions are: ① zero-nanometer materials, representative quantum dots; ② one-dimensional nanomaterials, including the most common carbon nanowire and nanotube; ③ two-dimensional nanomaterials; on the plane, nanoscale films and multilayer films of graphene; ④ Three-dimensional nanomaterials, such as fullerenes, which are hollow spheres in three-dimensional space, and the solid formed by the cross combination of these low dimensional materials. In a narrow sense, it refers to solid materials such as body materials and particulate film materials, which are formed by a single nanoparticle [2,3]. The properties of composite nanoporous materials contribute to the electrode Constraints in catalyst and chemical catalysis, select a specific composite component to prepare the compound Composite porous catalyst. According to these characteristics of porous materials can be better porous. The preparation of composite materials expands the application field of porous materials.

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Porous materials can be divided into two categories: biochar and metal.

Principle of biochar main If a solid material is produced by pyrolysis of biomass at high temperatures in an oxygen-free environment, This material comes from nature, is very common, and the cost is relatively low, More environmentally friendly, in the application of porous, large surface area can play a good repair effect.

Metals are mainly organic skeleton porous materials, which are also crystalline materials that gather pores and cause surface area to increase, and are metal atom clusters as component units, through the connection of organic ligands. The crystal structure and porous structure of the material provide the application after synthesis, which is also the main characteristic of porous materials.

The main principle is that the periodic topological structure is formed in the solid material when the metal atom cluster is the unit, and then through the ligand unit, the topological structure of the material is changed, and then different voids are formed, and this change depends on the metal-organic skeleton structure and the selected ligand unit, so that the operation is more flexible.

Because the structure of nanomaterials is fundamentally different from that of ordinary solid materials, and they are quite active in thermodynamic state, nanomaterials have many different effects on material properties, and thus derive some special properties that are not like the physical and chemical properties of macroscopic substances or the properties of microscopic atoms and molecules. These special properties include quantum size effect, volume effect (or small size effect), surface and interface effect, dielectric limit effect, macroscopic quantum tunneling effect, etc. It is worth noting that when the material has a part of the nanoscale composition, the performance of the nano-part and the non-nano-part of the material is completely different. In addition, nanomaterials also have the characteristics of: ① high hardness, plasticity; ② high specific heat and thermal expansion; ③ High conductivity and diffusivity; ④ High magnetic susceptibility and high coercivity. Moreover, the interaction between atoms and molecules in nanomaterials is more intense, which affects the macroscopic properties of objects. This gives nanomaterials a wider range of applications. For example, nanomaterials usually have higher chemical activity than ordinary materials and can be used as cathode of lithium batteries [4]. Its excellent optical and electromagnetic properties are also the focus of research in recent years.

2. Literature review

Nano-composite materials are based on the matrix of resin, rubber, ceramics and metals as a continuous phase, nano-sized metal, semiconductor, rigid particles and other inorganic particles, fibers, carbon nanotubes and other modifiers as a dispersed phase, through appropriate preparation methods to disperse the modifier uniformly in the matrix material, forming a phase containing nano-sized materials composite system. This system of materials is called nanocomposites.

At present, most studies on the modification mechanism of inorganic nanoparticles on polymers focus on toughening and strengthening. Some studies suggest that the existence of inorganic nanoparticles is easy to produce stress concentration effect. There are micro-cracks between the matrix and the matrix, that is, silver stripes. At the same time, there is plastic deformation between the particle and the matrix, which absorbs the impact energy and achieves the effect of plasticizing. The presence of inorganic nanoparticles inhibits and passivates the crack propagation of matrix resin, and prevents the crack from developing into destructive cracking. As the particle size decreases, the surface area of the particle increases and the contact area between the particle and the matrix increases. When the material is impacted, more microcracks and plastic deformation will occur, and more impact energy will be absorbed to improve the toughening effect. However, if the dosage is too much, the microcracks are easy to develop into macroscopic cracks, which will degrade the properties of the composites [5,6].

Compared with traditional nanomaterials, the structural advantages of composite nanomaterials are very obvious, which are reflected in the following aspects: First, because the traditional nanomaterials will be lost, agglomerated and destroyed in the process of application, while the nano-array materials can just avoid this phenomenon, because the nano-array materials grow in-situ on the substrate and are firmly connected. It has good stability, and successfully realizes the immobilization of nano-array materials, so as to avoid the loss, agglomeration and destruction of nanomaterials in the application process. Secondly, the nanounits are uniformly and orderly assembled on the surface of the substrate, so that the entire device material has a large specific surface area, which is greatly conducive to its application in heterogeneous catalysis, electrochemical electrodes, etc. Third, the process of controlling the synthesis reaction can effectively regulate the composition, size, substrate and morphology of the nanoarray, so that the nanoarray can meet different application needs.

Many have been prepared by polymer-embedded low melting point alloy bunching hot process Three good foot in the parameter club A low melting point alloy nanowire and polymer nanotube. The three-dimensional ruler of the nanowire array is adjusted across scales.

Using this method, the most convenient is that the spacing of the nanowires can be adjusted, but it is powerless to prepare high melting point alloys or metals.

Generally speaking, the investigation on the toughening mechanism of inorganic particles on polymer is mainly carried out around the matrix, inorganic particles, inorganic particles and the interface between the matrix. For the matrix, it is generally believed that the toughening effect is related to the relative molecular weight, intermolecular force, crystallinity and crystal shape of the matrix, and the performance is particularly related to the toughness of the matrix. In order to toughen inorganic particles, the matrix must have certain toughness and certain strength and toughness ratio. For inorganic particles, it is believed that the toughening effect depends on particle shape, particle size, particle distribution and particle content. For the interfacial action and interfacial phase, if the interfacial phase can ensure that the particles have a good combination with the matrix, and there is a certain thickness of the flexible layer, it is beneficial to cause the silver grain and stop the crack when the material is damaged. It can not only consume a lot of impact work, but also better transfer the external force, so as to achieve the purpose of toughening and strengthening [7].

Nano - CaCO₃ toughened PVC and PP composites were studied. In this essay, nano-cacO3 particles (inorganic rigid particles) are used to toughen the polymer, which belongs to the non-elastic toughening system. Compared with the toughening modification of elastomers (such as CPE, SBS, etc.), the toughening of nano-cacO3 particles has many advantages. The traditional toughening of elastomers increases the toughness (impact strength) of the material while reducing its rigidity (modulus). The toughness and rigidity of plastics can be improved comprehensively by using nano particles for toughening.

3. Research method

3.1. Overview of polymer precursor conversion methods

Since the concept of ceramic precursor polymer was put forward more than 30 years ago for the preparation of silicon-based advanced ceramics, the preparation of Si C fiber with polycarbosilane and industrialization, the process of polymer precursor conversion ceramics has been developed continuously, and its advantages and application prospects have gradually been recognized by people. As a new method to prepare ceramic materials, the polymer precursor conversion method has created a new field of using organic matter to prepare inorganic ceramic materials, and is a revolutionary innovation to the traditional powder sintering process to prepare ceramics. A kind of polymer material is synthesized by chemical method as precursor polymer, and the pyrolysis process is used to complete the transformation from organic

matter to inorganic matter [8,9]. Therefore, this process combines the characteristics of precursor molecule designability and the processing method similar to traditional polymer. It has potential application prospect in the preparation of ceramic materials with specific composition (Si-C, Si-O-C, Si-C-N or Si-B-C-N) and diversified morphology (bulk, fiber, film, tube, foam and porous structure).

3.1.1. Basic process of preparing ceramics by polymer precursor conversion

Polymer Derived Ceramics (PDCs) are an important method to produce Si based ceramics, which mainly involves the following steps: (1) Precursor oligomers or polymers are synthesized by chemical methods, (2) precursor oligomers or polymers are crosslinked and solidified at a certain temperature, (3) the precursor is decomposed into amorphous ceramics at a lower temperature (700–1000 °C), and (4) amorphous ceramics form crystalline phases at higher temperatures. At present, the precursor conversion method for the preparation of ceramic materials has been rapidly developed, and its advantages and potential are gradually recognized by people, and become the research hotspot of advanced ceramics [10]. The technological process of precursor conversion method is shown in Fig. 1.

3.1.2. Characteristics of the polymer precursor conversion method

Different from traditional ceramic preparation technology, the polymer precursor conversion ceramic technology uses organic polymer as raw material and produces ceramic materials through pyrolysis process, thus overcoming many shortcomings of powder sintering ceramic preparation process (high sintering temperature, poor technology).

- 1) Designability of precursor molecules. Precursor polymers represent organic/inorganic systems. According to the actual requirements, the precursor of the required element composition and molecular weight can be synthesized through molecular design to realize the design of ceramic materials.
- 2) Good processability. Using organic precursor polymers, intermediate products of desired strength can be obtained at lower temperatures using traditional polymer molding methods (polymer dip cracking (PIP), extrusion molding, injection molding, resin transfer molding (RTM)), allowing for easy next processing and densification of the material. Therefore, the polymer precursor transformation method can prepare ceramic products with complex shapes [11].
- 3) Good manufacturability. The traditional method of preparing ceramics requires the addition of sintering additives, so its application is severely limited. PDCs are directly derived from precursor polymers, so they can prepare ceramic fibers, films, lamellar structures and composite materials of various shapes that cannot be obtained by traditional technology.

- 4) Low sintering temperature. The traditional preparation process of ultra-high temperature oxidation resistant ceramics is complicated, which usually requires hot pressing sintering above 1500 °C. However, the ceramic precursor can be crosslinked and solidified at low temperature without adding any sintering additives to prepare high temperature resistant ceramics.
- 5) Prepare advanced ceramic materials. There are no other additives in PDCs, so they have excellent high temperature oxidation resistance and creep resistance [12].

The preparation of ceramic materials by polymer precursor conversion also has inherent shortcomings, which are mainly manifested in the following two aspects.

- 1) When the precursor cracks, small molecular gases are released and many pores are produced, thus affecting the high temperature performance of the material. 2) Due to the escape of small molecular gases during cracking, the precursor will produce large volume shrinkage, which may cause deformation and cracking of the matrix. In order to solve these problems, polymers containing reactive groups, rings and branched structures can be designed to reduce the porosity during pyrolysis. In short, the precursor conversion method has become one of the important methods to prepare advanced functional ceramics and composite materials.

3.1.3. Application of polymer precursor conversion ceramics (PDCs)

Due to its excellent physico-chemical properties, unique functionality and numerous processing methods, PDCs materials have been used in some key fields, such as information technology, transportation, energy, environment, biomedicine, MEMS/NEMS and national defense fields.

(1) Ceramic fiber

Ceramic fibers are the oldest and most successful application of ceramic precursor polymers. With the development of polymer precursor technology, the fiber can be prepared for ceramic matrix composites as well as improve fiber properties. With the deepening of research and the improvement of processing methods, the oxygen pollution content of SiC fibers decreased from 15 % to 0.5 %, which greatly improved the high temperature stability while maintaining the original mechanical strength (2.6–3.3 GPa). In addition, ceramic fibers with excellent structural stability and oxidation resistance can be prepared by adding B and N elements into the PCS. Its strength is equivalent to SiC fiber, and it can maintain amorphous structure at 1700 °C. In addition, oxidation resistance and creep properties are also greatly improved. Other research achievements include the preparation of BN fiber and Si CN

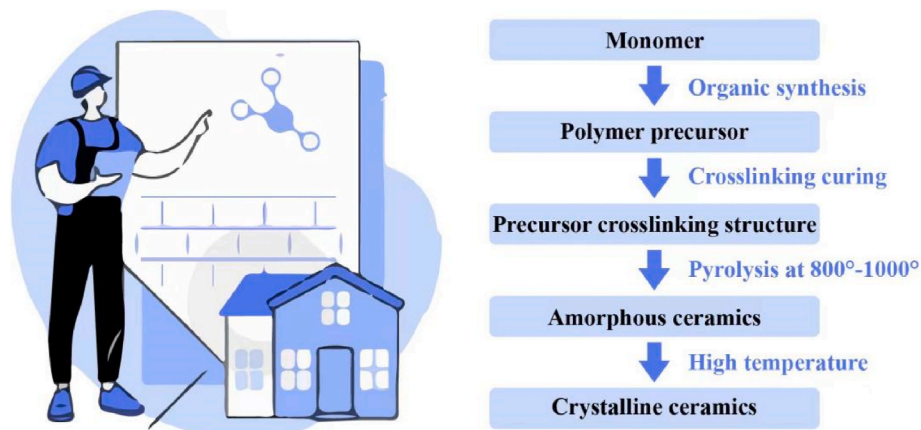


Fig. 1. Technical route of ceramic materials prepared by polymer precursor conversion.

fiber containing multi-arm carbon nanotubes; For the latter, the tensile strength of fibril and pyrolytic products increased by 100 % and 50 %, respectively, after the addition of 1 wt% MWCNTs [13,14].

(2) Ceramic film

An important feature of the polymer precursor conversion process is the preparation of low dimensional products, such as ceramic coatings. Depending on the phase state of the ceramic precursor polymer (molten, solution, or gas phase), different deposition techniques can be used to deposit the precursor polymer on the substrate. The precursor polymer can be modified by loading different fillers to increase the thickness of the ceramic film without forming cracks during deposition. In addition, the processing temperature can be reduced to reduce damage to the substrate.

The polymer precursor conversion method has prepared SiC, Si CO and BN ceramic films, which are mainly used in the interface control of carbon fiber composites and anti-oxidation protection and photoelectric effect films (such as light-emitting diode films). Compared with traditional oxidizing glass or ceramic films, Si CN films have excellent high temperature resistance, acid and alkali corrosion resistance and wear resistance, which is expected to be used in wear or corrosion protection, micro electrical equipment and photoelectric equipment [15].

(3) Porous ceramics

The preparation of ceramics by polymer precursor conversion has two remarkable characteristics: (1) The precursor produces a large amount of pyrolysis gas during pyrolysis, leaving many pores in the ceramic matrix; (2) Volume shrinkage and density increase during thermal decomposition of precursor. Therefore, ceramic materials with wide pore size distribution (from a few nanometers to a few millimeters) and high porosity (<70 vol %) can be prepared by different processing methods.

In addition, the polymer precursor conversion method can also be used to adjust the specific surface area and properties of the material (e. g. electromagnetism) by adding suitable fillers to the precursor or changing the processing parameters. Such as using hydrofluoric acid (preparation of Si CO ceramics) or chlorine gas (preparation of SiC or SiCN ceramics) for etching, can prepare large surface area, high content of microporous mesoporous carbon based ceramic materials.

(4) ceramics and composite materials

Precursor polymers (usually containing ceramic powder fillers) can also be used to prepare ceramic matrix composites. Si C fiber reinforced Si C matrix composites were prepared by polymer impregnation pyrolysis (PIP), which included several cycles of impregnation, solidification, densification, re-impregnation and pyrolysis to reach the final densification, so the preparation process was also called precursor impregnation-pyrolysis (PIP) (as shown in Fig. 2). Compared with CVI or melt penetration method, this technology has the advantages of simple preparation process, low equipment cost, low processing temperature (reduce the damage to ceramic fiber during processing), short operation

cycle, and can also prepare large size (thickness up to 45 cm) and complex products. With the increase of the yield of ceramic materials prepared by ceramic precursor system, the impregnation cycle can be shortened effectively and the preparation cycle of materials can be reduced. In addition, parts can be machined into a network shape before densification and do not require extensive subsequent processing.

(5) Micro-electromechanical System (MEMS)

Potential applications of polymer precursors to ceramics are ceramic micro-electro-mechanical systems (MEMS) in optical devices or mechanical materials. There are the following requirements for the preparation of Si based polymers for MEMS:

The polymer or solidified polymer should be able to infiltrate the micromold sufficiently (the polymer can maintain its shape by chemical or thermal crosslinking when the mold is fully filled and is easy to release); Ceramic MEMS were then prepared by pyrolysis. When preparing ceramic MEMS, a variety of active (Ti, TiH₂, Al, etc.) or inert (SiC, Al₂O₃, TiB₂) fillers can be added to the precursor polymer to fully mix, and then the mixture is pyrolyzed into Si CO ceramics under different atmospheres [16].

In addition to the above applications, precursor converted Si CN ceramic materials can also be used as anode materials for lithium ion batteries. Because of the good chemical stability in the corrosive environment, the graphite can be protected from falling off during the charge - discharge process. More importantly, because Si CN ceramics contain disordered carbon phase, it can provide sufficient permeation path for lithium ion and electron embedding/deembedding process.

3.2. Experiment

As nano-CaCO₃ toughened PVC and PP system belong to non-elastic toughening, the matrix itself is required to have a certain toughness, so a small amount of elastomer should be added to PVC or PP, CPE can be added to PVC, SBS can be added to PP. In this study, nano-caco3/PVC/CPE composites and nano-Ca-Co3/PP/SBS composites were prepared. The results show that the addition of nano-CaCO₃ particles can significantly toughen the materials. Nano CaCO₃/PVC/CPE composite material was applied to the profile of PVC doors and Windows, and the performance of the profile of PVC doors and Windows was improved comprehensively.

3.2.1. Raw materials

- (1) Nano CaCO₃: Made by a university's high gravity Engineering technology research center using the high gravity technology, the average particle size of 30 nm, after wet surface modification, and further pretreatment.
- (2) PVC resin: SG-5.
- (3) Chlorinated polyethylene (CPE): 36 % chlorine content.
- (4) PP resin.
- (5) SBS.
- (6) Other auxiliaries (stabilizer, processing auxiliaries): All of them are industrial grade.

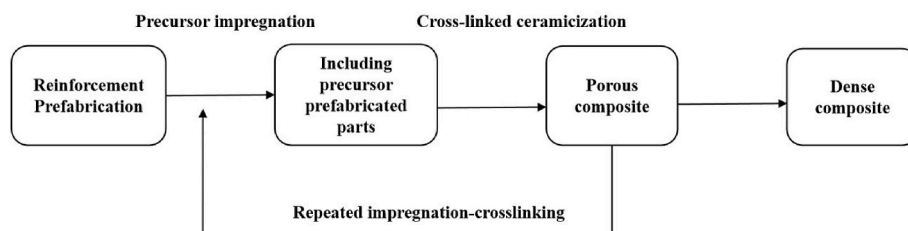


Fig. 2. Flow chart of preparation of ceramic matrix composites by PIP method (Precursor infiltration and pyrolysis).

3.2.2. Experimental equipment and methods

The sample of nano CaCO_3 /polymer composite prepared in the laboratory was made by single screw extrusion mechanism. The impact performance was tested by simply supported beam impact testing machine. The test method was carried out according to GB 1043-79 "Impact Test Method for Plastic simply supported Beams". Instron tensile testing machine was used to test tensile and bending properties. The industrial test of the profile of PVC doors and Windows was carried out in the profile manufacturing factory. The performance test is carried out in accordance with GB 8814-1998 "Hard polyvinyl chloride (PVC) Profiles for Door and Window Frames".

4. Result analysis

4.1. Impact resistance of nano CaCO_3 /PVC/CPE composites

The effects of different amounts of nano- CaCO_3 on notched impact strength of nano- CaCO_3 /PVC/CPE composites were studied. The single notch spline was prepared by using a single screw extrusion machine. The test method was carried out according to GB1043-79, and the results were shown in Table 1.

The results in Table 1 show that the notch impact strength of the sample increases significantly with the addition of nano- CaCO_3 . When the mass ratio of PVC to nano- CaCO_3 to CPE is 100:8:8, the notched impact strength of the composite sample can reach 81.4 kJ/m², which is 4.46 times higher than that of the sample without nano- CaCO_3 , indicating that nano- CaCO_3 has a significant toughening effect on PVC composites.

In order to improve the performance of nano- CaCO_3 /polymer composites, the key is to make the nanoparticles dispersed evenly in the polymer. However, the surface energy of nanoparticles is very high. If the nano- CaCO_3 without proper treatment is directly added to the polymer, the nanoparticles are easy to aggregate into clusters and cannot play the role of toughening. In this study, special surface treatment agent was used to modify the surface of nano CaCO_3 particles, and further pretreatment was carried out. The prepared modified nano CaCO_3 has significant toughening effect on PVC/CPE [17].

4.2. Tensile and bending properties of nano CaCO_3 /PVC/CPE composites

The tensile strength, elongation at break and flexural elastic modulus of nano- CaCO_3 /PVC/CPE composites are shown in Table 2.

As can be seen from Table 2, the bending elastic modulus of the sample with nano- CaCO_3 added increases compared with the sample without nano- CaCO_3 added. Compared with the data in Table 1, the impact strength and bending elastic modulus are both improved by the addition of nano- CaCO_3 , which is exactly the advantage of nano- CaCO_3 particle toughening. It can also be seen from Table 2 that the tensile strength of the sample with nano- CaCO_3 added is basically the same as that without nano- CaCO_3 added. The elongation at break increased obviously [18,19].

Table 1

The relationship between the amount of nano- CaCO_3 and the impact strength of PVC/CPE notch.

Sample number	Amount of main materials (mass parts)			Notched impact strength/(kJ/m ²)
	PVC	Nano CaCO_3	CPE	
1	100	0	8	14.8
2	100	4	8	53.7
3	100	8	8	81.4

Table 2

Tensile and bending properties of nano CaCO_3 /PVC/CPE composites.

Sample number	Quantity of main materials (mass parts)			Tensile strength/MPa	Elongation at break/%	Bending modulus of elasticity/MPa
	PVC	Nano CaCO_3	CPE			
1	100	0	8	38.7	61	2180
2	100	0	8	38.6	147	2210

4.3. Impact resistance of nano CaCO_3 /PP/SBS composites

The notched impact strength of nano- CaCO_3 /PP/SBS composites is shown in Table 3 and Fig. 3.

The experimental results showed that the notch impact strength increased by 15.8 % from 46.8 kJ/m² to 54.2 kJ/m² when two nano- CaCO_3 was added into the PP/SBS blend system, indicating that nano- CaCO_3 also toughened PP to some extent.

4.4. Performance of nano CaCO_3 /PVC composite door and window profiles

The industrial test of nano CaCO_3 /PVC composite door and window profiles was carried out in profile manufacturing plant. 80 series of push-pull window frame profiles were extruded by adding 2.6 parts of pre-treated nano- CaCO_3 to the commercial pilot production formula. The properties of profiles are tested by National Chemical Building Materials Testing Center, and the test results are shown in Table 4.

The results show that the profile with nano- CaCO_3 added can not only guarantee the impact performance of low-temperature drop hammer, but also significantly improve the notched impact strength, tensile strength, elongation at break and flexural modulus of the simply supported beam compared with the profile without nano- CaCO_3 added. Nano CaCO_3 /PVC/CPE composites can also be applied to PVC pipe. After further research and development, nano CaCO_3 /PP/SBS composites can also be applied in PP pipes [20].

5. Conclusion

- (1) The notched impact strength of nano- CaCO_3 /PVC/CPE composite reaches 81.4 kJ/m², which is 4.46 times higher than that of PVC/CPE composite without nano- CaCO_3 , indicating that nano- CaCO_3 has significant toughening effect on PVC/CPE. At the same time, the flexural elastic modulus of the composites is also improved, indicating that the toughness and rigidity of the composites can be improved by the toughening of nano- CaCO_3 toughened PVC/CPE as a non-elastic body.
- (2) Nano- CaCO_3 also has a toughening effect on PP/SBS.
- (3) The profile with nano- CaCO_3 added can ensure the impact performance of low temperature drop hammer, while the notched impact strength, tensile strength, elongation at break and bending modulus of the simply supported beam are significantly improved compared with the profile without nano- CaCO_3 added.

Table 3

Notch impact strength of nano CaCO_3 /PP/SBS composites.

Sample number	Quantity of main materials (mass parts)			Notched impact strength/(kJ/m ²)
	PP	Nano CaCO_3	SBS	
4	100	0	0	14.7
5	100	0	10	46.8
6	100	2	10	54.2

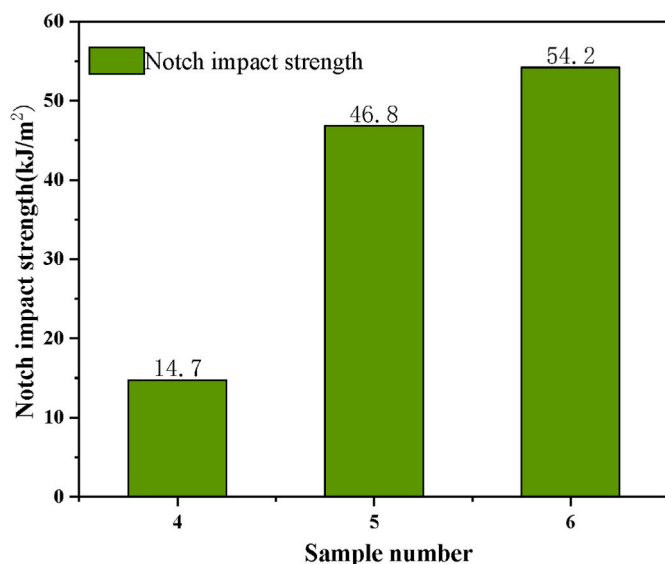


Fig. 3. Notched impact strength of nano CaCO₃/PP/SBS composites.

Table 4

Properties of nano-cacO₃/PVC composite door and window profiles.

Project	National standard requirement	Test result
Hardness/HRR	≥85	92.1
Tensile yield strength/MPa	≥37.0	42.5
Elongation at break/%	≥100	156
Bending modulus of elasticity/MPa	≥1960	2566
Notched impact strength of simply supported beam (23 ± 2 °C)/(kJ/m ²)	≥40	62.3
Notched impact strength of simply supported beam (−10 ± 1 °C)/(kJ/m ²)	≥15	72.0
Vica softening temperature/°C	≥83	85.3
Oxygen index/%	≥38	45.4
Low temperature drop hammer impact damage/(PCS/10 times)	≤1 / 10	0 / 10
After heating state	No bubbles, cracks, pitting	No bubbles, cracks, pitting
Size change rate after heating/%	±2 . 5	- 2 . 3

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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