SPE
SOCIETY OF PLASTICS ENGINEERS
Plastics Research Online
10.2417/spepro.006340

Carbide slag as a filler in poly(vinyl chloride)/wood composites

Shenghui Tian and Hui He

Using an industrial waste as an inorganic filler in plastic/wood composites improves the fire and mechanical properties of the material, as well as reducing its financial and environmental cost.

Carbide slag (CS) is an industrial-waste material produced by calcium carbide hydrolysis in the preparation of acetylene gas. Chemical industries produce a million tons of CS per year, thereby creating a large amount of environmental pollution.[1,2] Moreover, the rate at which waste CS is being produced is growing rapidly. For these reasons, recycling this material represents an important challenge not only from the perspective of waste treatment but also in terms of the recovery of valuable materials.[3]

Awareness surrounding the issue of solid-waste pollution has been growing in recent years as people continue to seek solutions for a cleaner planet. As a result of this, interest in CS recycling has increased. There are several basic ways that currently make comprehensive use of CS (e.g., cement production and wastewater treatment).[4,5] Compared to the total amount of waste CS, however, the amount that is currently being recycled is far from enough. This has prompted the exploration of a number of novel approaches with the aim of enabling the comprehensive use of CS.

We have developed a method for the effective use of CS as a raw material in the fabrication of poly(vinyl chloride)/wood (PVC/wood) composites.[6] This method is based on our investigations into the influence that different contents and coupling-agent modifications have on the mechanical and fire properties of fabricated composites.

CS consists primarily of calcium hydroxide—$Ca(OH)_2$—and contains a number of impurities (e.g., silicon dioxide, aluminum oxide, iron oxide, and magnesium oxide): see Figure 1(a). CS represents a useful filler in the fabrication of plastics because of its superior dispersibility, heat resistance, and stability.[7] In particular, the presence of $Ca(OH)_2$ enables the use of CS as a novel smoke suppressant in PVC composites. CS has a wide particle distribution, with a median diameter of 8.1μm. Of the particles that we used, the majority (48.8wt%)

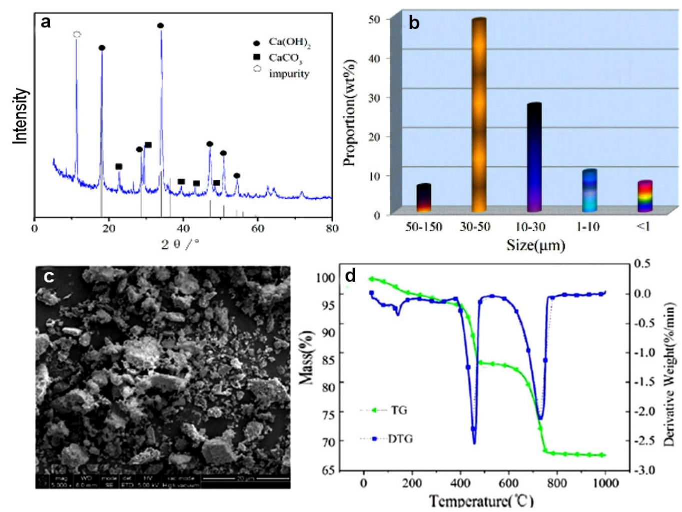

Figure 1. (a) X-ray diffraction patterns of the carbide slag (CS). θ: Diffraction angle. $Ca(OH)_2$: Calcium hydroxide. $CaCO_3$: Calcium carbonate. (b) Particle-size distribution of the CS. (c) Scanning-electron micrograph of CS. (d) Thermogravimetric (TG) and differential thermogravimetric (DTG) analysis.

were between 30 and 50μm: see Figure 1(a). The shape of the CS varies depending on the particle size: see Figure 1(d). We sampled and coarse-crushed the CS in a factory, and to confirm the median particle size was less than 100μm, we pulverized the particles in a high-speed pulverizer. We subsequently sifted these particles to eliminate the impurities and oversized particles. To study the thermal properties of the material, we used thermogravimetric analysis with a constant heating rate of 10°C/min (from ambient temperature to 1000°C) under a pure nitrogen flow (20mL/min). We found that the maximum weight-loss rate occurs at 450°C as a result of the thermal decomposition of $Ca(OH)_2$: see Figure 1(d).

Continued on next page

SPE Plastics Research Online
SOCIETY OF PLASTICS ENGINEERS
10.2417/spepro.006340

To improve the properties of CS and thereby increase its applicability, we used a silane coupling agent (KH570) as a modifier to create MCS (modified CS). The chemical reaction mechanism between KH570 and CS occurs in two steps: see Figure 2(a). In the first step, the coupling agents react with water molecules in the 95% by volume ethanol, causing hydrolysis and polycondensation to occur. The silanol group then reacts with hydroxyl on the surface of the CS particles. As a result of this behavior, interfacial adhesion between the PVC/wood composites and the MCS filler (20 parts per hundred resin, phr, based on 100phr PVC) is improved, resulting in an increase in the notched-impact strength of approximately 60% (from 2.63 to 3.87KJ/m^2). The mechanical properties (notched-impact strength, tensile strength, flexural strength, and flexural modulus) of the PVC/wood composites are shown in Figure 2(b–e).

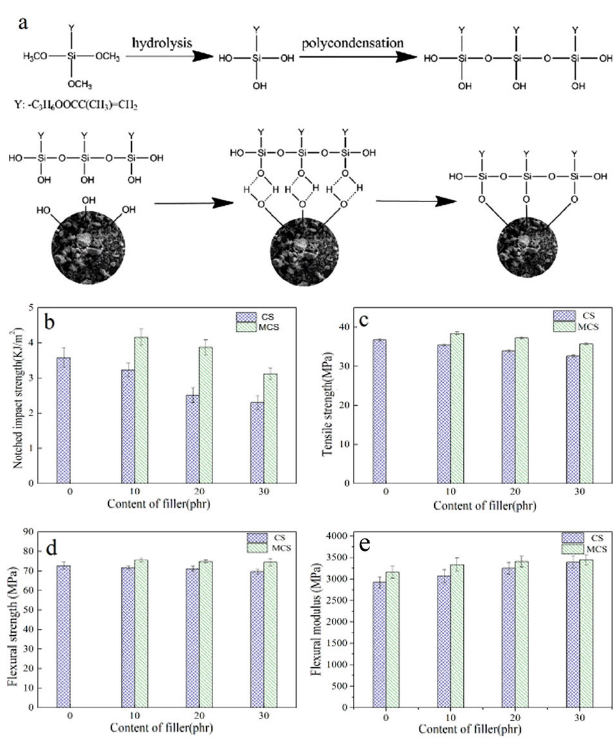

Figure 2. (a) Reaction between the surface of the CS and the silane coupling agent (KH570). First, the KH570 reacts with water molecules in the 95% by volume ethanol, causing hydrolysis and polycondensation. The silanol group subsequently reacts with the hydroxyl on the surface of the CS particles, creating modified CS (MCS) and increasing the interfacial adhesion between the CS and the PVC/wood composites. (b–e) The mechanical properties of PVC/wood composites filled with CS and MCS. The wood and CS/MCS components make up 20 parts per hundred resin (phr), respectively, based on 100phr PVC. (b) Notched impact strength. (c) Tensile strength. (d) Flexural strength. (e) Flexural modulus.

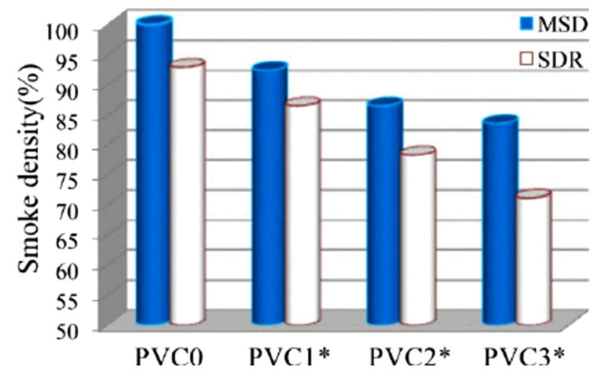

Figure 3. *The smoke-suppressing properties of PVC/wood composites modified with MCS. PVC 0: Neat PVC/wood composites. PVC1*, PVC2*, and PVC3*: PVC/wood composites with 10, 20, and 30phr MCS, respectively.*

Numerous toxic gases and fumes are released during the combustion of PVC/wood composites. These byproducts are even more dangerous than the fire itself. To determine the extent to which MCS mitigates this effect, we evaluated its smoke-suppressing properties in terms of its smoke-density rating (SDR) and maximum smoke density (MSD): see Figure 3. The neat PVC/wood composite produces a great deal of black smoke when burning, with an MSD value approaching almost 100%. In the case of composites treated with MCS, however, the SDR and MSD values significantly decrease as MCS content increases. An addition of 30phr MCS leads to a reduction in the SDR of 28% (from 73.9 to 46%) and in the MSD of 22% (from 93 to 71.1%). In addition to increasing the flame-retarding and smoke-suppressing properties of the composites, the MCS also significantly reduces the cost of the material.

The use of CS—a byproduct of the PVC manufacturing industry—as a filler in PVC/wood composites enables the complete recycling of this reusable resource. Additionally, the manufacturing costs are reduced and the thermal properties improved. The incorporation of MCS also substantially increases the flexural, tensile, and impact strengths of the PVC/wood composites. Moreover, as a result of the synergistic effects of the constituent materials, the SDR and MSD are significantly reduced (by 28 and 22%, respectively). The best mechanical properties were obtained with composites containing 20phr MCS. In our future work, we will concentrate on the processing performance of PVC/wood composites modified with MCS.

Continued on next page

Author Information

Shenghui Tian and Hui He
South China University of Technology
Guangzhou, China

References

1. Y. Li, H. Liu, R. Sun, S. Wu, and C. Lu, *Thermal analysis of cyclic carbonation behavior of CaO derived from carbide slag at high temperature*, **J. Therm. Anal. Calorim. 110**, pp. 685–694, 2011.
2. J. X. Cao, F. Liu, Q. Lin, Y. Zhang, Y. G. Dong, and L. K. Zeng, *Effect of calcination temperature on mineral composition of carbide slag, lime activity, and synthesized xonotlite*, **Key Eng. Mater. 368–372**, pp. 1545–1547, 2008.
3. J. X. Cao, F. Liu, Q. Lin, and Y. Zhang, *Hydrothermal synthesis of xonotlite from carbide slag*, **Key Eng. Mater. 18**, pp. 1147–1153, 2008.
4. S. Sun, C. Li, L. Zhang, H. L. Du, and J. S. Burnell-Gray, *Effects of surface modification of fumed silica on interfacial structures and mechanical properties of poly(vinyl chloride) composites*, **Eur. Polym. J. 42**, pp. 1643–1652, 2006.
5. J. Guo, J. Li, Q. Rao, and Z. Xu, *Phenolic molding compound filled with nonmetals of waste PCBs*, **Environ. Sci. Technol. 42**, pp. 624–628, 2008.
6. S. Tian, H. He, and H. Chen, *Mechanical, flammability, and thermal properties of polyvinyl chloride-wood composites with carbide slag*, **Polym. Compos.**, 2015. First published online: 29 December. doi:10.1002/pc.23893
7. H. Qu, C. Liu, W. Wu, L. Chen, and J. Xu, *Using cone calorimeter to study thermal degradation of flexible PVC filled with zinc ferrite and* $Mg(OH)_2$, **J. Therm. Anal. Calorim. 115**, pp. 1081–1087, 2014.