

Vulcanization Process and Properties of Conductive Silicone Rubber Filled With Silver-coated Carbonyl Nickel Powder

Weimin Xiao^{1,a}, Yongping Lei^{1,a}, Zhidong Xia^{1,a}, Jingkai Nie^{2,b}

¹School of Material Science and Engineering, Beijing University of Technology, 100 Ping Le Yuan, Chaoyang District, Beijing 100022, PR China

²Global Energy Interconnection Research Institute, Future City for Science and Technology, Changping District, Beijing 102209, PR China

^aemail: 13522261603@126.com

^bemail: jknie@emails.bjut.edu.cn

Keywords: Carbonyl nickel powder; silver coating; conductive silicone rubber; electromagnetic shielding property; vulcanization process.

Abstract: The article investigates the effect of vulcanization process on electromagnetic shielding and mechanical property of the conductive silicone rubber filled with the silver-coated carbonyl nickel powder. The results show that the post curing process can remarkably improve the electromagnetic shielding effectiveness (SE) in the frequency range of 100-1200MHz. The SE of the rubber with the post curing process obtains a average increase of 25% compared with the primary curing process. In addition, it is also found that different curing process has no significant influence on the mechanical property of the rubber. The performance in the property is attributed to the formation of a better conductive-particle network structure in the rubber and strong connection between the powder particles and the rubber matrix when the post curing process is used instead of the primary curing process.

Introduction

Electromagnetic pollution has become a serious environmental problem for several years. To improve the electromagnetic pollution protection, a number of materials have been researched in the recent years. Conductive silicone rubber, as a kind of electrical connection materials between electromagnetic shielding materials in the environmental engineering projects, plays an important role in the electromagnetic protection. The materials include polymer composites filled with nickel-coated carbon fiber, nickel-coated graphite, silver-coated cenospheres and so on[1-3].

It is well known that the fillers have a significant influence on the electromagnetic property of the composites. Common fillers include metals (e.g. copper powder), carbon materials (e.g. carbon fibers) and core-shell particles (e.g. silver-coated cenosphere), which possess relatively high conductivity and are beneficial to enhancement of electromagnetic wave reflection [3-7]. Another fillers include the particles of dielectric or magnetic dipoles (e.g. Co/SiO₂ nanosphere core-shell composites and carbonyl iron/nickel powder), which can absorb and attenuate the incident electromagnetic wave, then crunch the electromagnetic energy into heat energy, or weaken the electromagnetic waves' interference [8-10].

Carbonyl nickel powders have been widely applied in the industry as a kind of magnetic absorber and filler due to high saturation magnetization, superior stability, and enhanced dispersion [11-14]. Recently, it has been proved that the silver coating on the carbonyl nickel powder can improve the electromagnetic shielding effectiveness (SE) of the powder[15].

However, little work has been carried out for understanding the effects of the vulcanization process on the electromagnetic wave shielding properties of the conductive silicone rubber filled with the silver-coated carbonyl nickel powder. Considering the excellent magnetic property and well-defined structure of the silver-coated carbonyl nickel powder, the improved vulcanization process may provide another good choice for the electromagnetic property improvement. Therefore, the effect of

the vulcanization process on the electromagnetic shielding property of the material is discussed and the microstructure is analyzed in the paper.

Experimental procedure

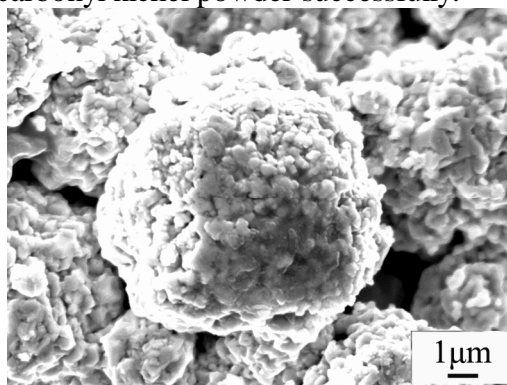
The conductive silicone rubber filled with the silver-coated carbonyl nickel powder was prepared by mixing the pure silicone rubber, vulcanizing agent and silver-coated carbonyl nickel powder at 15°C for 2 hours in the double planetary mixing equipment. The mixture was poured into a 200 × 200 mm stainless picture-frame mold with a thickness of 2 mm. The mold was placed in a plate vulcanizing instrument at 165°C curing temperature with inert-gas protection. Pressure of 10 MPa was applied and held for 5 min to get a group of the conductive silicone rubber sheets. After that, the sheets were kept at room temperature (20±5°C) for 1 h and then placed in a plate vulcanizing instrument at 165°C curing temperature with inert-gas protection again. Finally, the sheets were kept at room temperature (20±5°C) for 24h before test. The mass ratio of the silver-coated carbonyl nickel powders to pure silicone rubber was 300:100.

Scanning electron microscopy (SEM) (ZEISS EVO18, ZEISS Ltd., Germany) was used to observe the distribution of fillers of the composites. The elemental distribution was evaluated by energy-dispersive x-ray analysis (EDX).

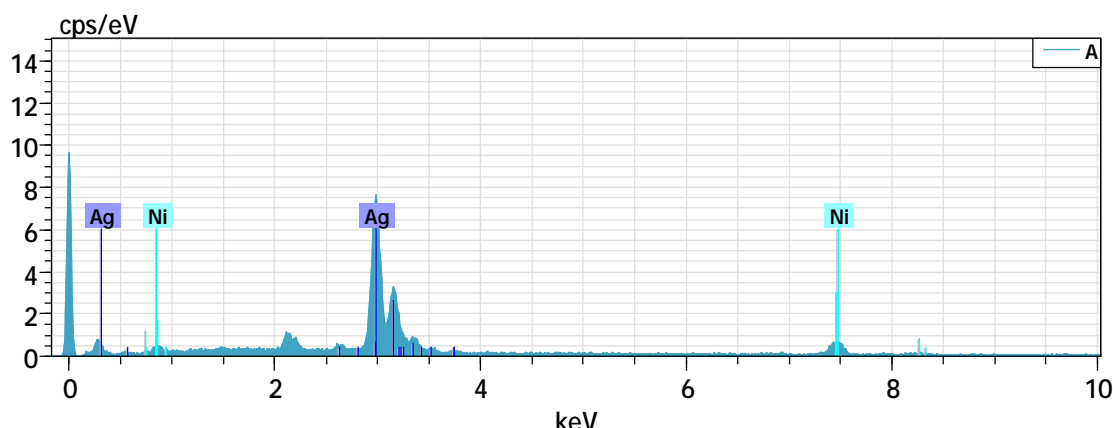
The SE of the sample for plane-wave conditions was measured by means of the flange coaxial method. The setup consisted of a DN15115 SE tester which was connected to an Agilent 4396B RF network spectrum impedance analyzer. The scanning frequency ranged from 100 MHz to 1.5 GHz. The thickness of the rubber layers were 2 mm.

Results and discussion

Fig.1 shows (a) the microstructure of the silver-coated carbonyl nickel powder and (b) the EDX patterns of the silver-coated carbonyl nickel powder. It is observed that the compact and uniform silver coating layer covers on the surface of the powder in Fig.1 (a). The EDX patterns in Fig.1 (b) reveal that the carbonyl nickel powder is mainly composed of the nickel element and the silver coating layer has covered on the surface of the carbonyl nickel powder successfully.



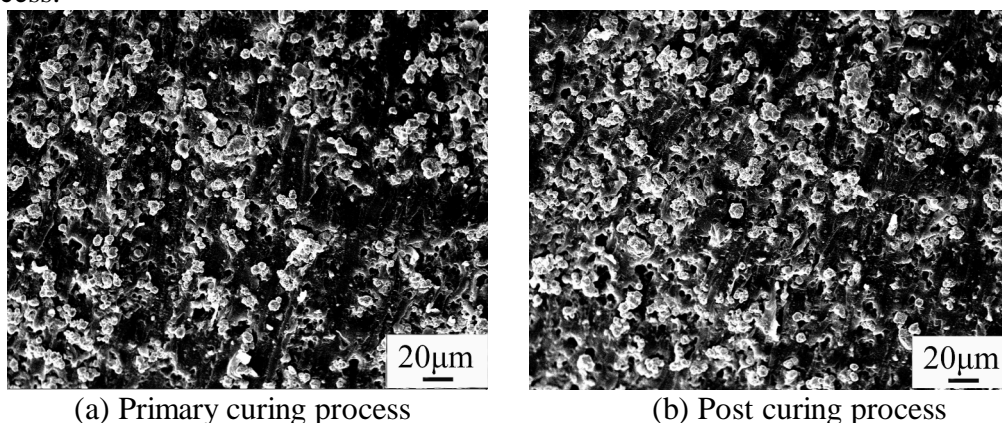
(a) Microstructure of the silver-coated carbonyl nickel powder



(b) EDX patterns of the silver-coated carbonyl nickel powder

Fig.1 Microstructure and EDX patterns of the silver-coated carbonyl nickel powder

Fig.2 shows the tensile fracture morphology of the conductive silicone rubber filled with the silver-coated carbonyl nickel powder with (a) primary curing and (b) post curing process. It is detected that the lamellar tearing exists in the rubber specimens with primary curing and post curing process. Compared with the morphology of the specimen with primary curing process, a close relationship is built between the powder particles and the rubber matrix in the morphology of the specimen with post curing process.



(a) Primary curing process

(b) Post curing process

Fig.2 Fracture morphology of conductive rubber filled with the powder at different curing process

Fig.3 shows the variation in the electromagnetic shielding effectiveness (SE) of the conductive silicone rubber filled with the silver-coated carbonyl nickel powder with primary curing and post curing process. It is found that the post curing process can remarkably improve the electromagnetic shielding properties in the frequency range of 100-1200MHz. As seen in Fig.3, the SE of the rubber with the post curing process obtains a average increase of 25% compared with the primary curing process.

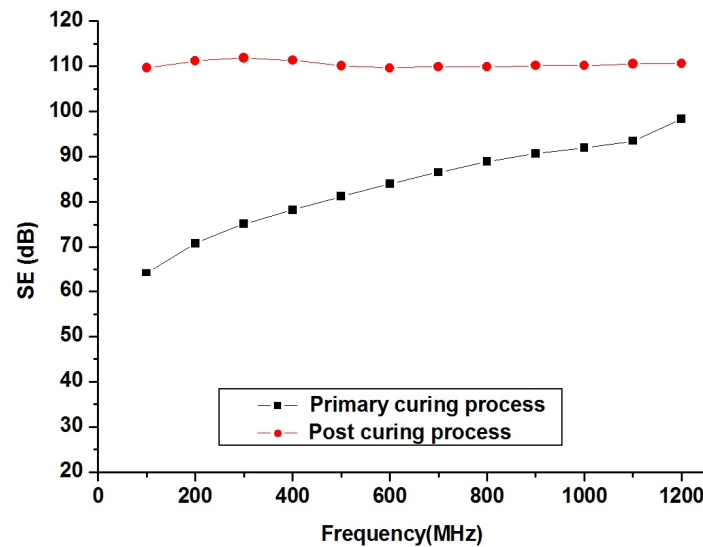


Fig.3 The SE of conductive rubber filled with the powder at different curing process

Table 1 indicates the mechanical properties of the conductive silicone rubbers filled with the silver-coated carbonyl nickel powders at different curing process. From the table, it is seen that the tensile strengths and elongation at break of the samples is roughly identical. The different curing process has no significant influence on the mechanical property of the rubber.

Table 1 Mechanical property of the samples at different curing process

Curing process	Ultimate tensile strength (MPa)	Elongation (%)
Primary curing process	2.92	283
Post curing process	2.87	276

The performance in the electromagnetic and mechanical property is related to the strengthening effects of the post curing process on the rubber. As is seen in Fig.2, the rubber with the post curing process has a more compact microstructure than that with the primary curing process. The post curing process may promote the decomposition of the vulcanizing agent and activate the methyl and vinyl groups on the molecular chain better than the primary curing process. That means that more cross-bonds can be generated between the molecular chains, which builds a close relationship between the powder particles and the rubber matrix. The close relationship leads to a better conductive-particle network structure in the rubber and strong connection between the powder particles and the rubber matrix. The conductive-particle network structure and the strong connection plays an important role in electromagnetic shielding and mechanical property of materials. Therefore, the electromagnetic property is improved and the mechanical property is retained when the post curing process is used instead of the primary curing process.

Conclusions

The effect of the different curing process on electromagnetic and mechanical property of the conductive silicone rubbers filled with silver-coated carbonyl nickel powders is analyzed. It is found that the post curing process can remarkably improve the electromagnetic shielding properties in the frequency range of 100-1200MHz. the SE of the rubber with the post curing process obtains a average

increase of 25% compared with the primary curing process. In addition, it is also found that different curing process has no significant influence on the mechanical property of the rubber. The performance in the property is related to the strengthening effects of the post curing process on the rubber. The rubber with the post curing process has a more compact microstructure than that with the primary curing process, which builds a close relationship between the powder particles and the rubber matrix. The close relationship leads to a better conductive-particle network structure in the rubber and strong connection between the powder particles and the rubber matrix. As a result, the rubber with the post curing process obtains better electromagnetic than that with the primary curing process and good mechanical property is retained.

Acknowledgements

The authors greatly appreciate the financial support by Science & Technology Project of State Grid Corporation of China (5455DW160004).

References

- [1] R. Wang, H. Yang, J. Wang, G. Li. *Polym: Test*. Vol 38 (2014), p. 53.
- [2] Zou H, Zhang LQ, Tian M, Wu SZ, Zhao SH: *J. Appl. Polym. Sci*. Vol 775 (2010), p. 2710.
- [3] Yong-jun Hu, Hai-yan Zhang, Feng Li, Xiao-ling Cheng, Tian-li Chen: *Polymer Testing*. Vol 29, (2010), p. 609.
- [4] D.I. Petukhov, M.N. Kirikova, A.A. Bessonov, M.J.A. Bailey: *Mater. Lett*. Vol 132 (2014), p. 302.
- [5] Mohd Yusuf Zakaria, Abu Bakar Sulong, Jaafar Sahari, Hendra Suherman: *Composites Part B: Engineering*, Vol 83 (2015), p.75.
- [6] Faris M. AL-Oqla, S.M. Sapuan, T. Anwer, M. Jawaid, M.E. Hoque: *Synthetic Metals*, Vol 206 (2015), p. 42.
- [7] X.G. Cao, H.Y. Zhang: *Appl. Surf. Sci*. Vol 264 (2013), p. 756.
- [8] X.J. Yin, K. Peng, A.P. Hu, L.P. Zhou, J.H. Chen, Y.W. Du: *J. Alloys Comp*. Vol 479(2009) , p. 372.
- [9] Z. Song, J. Xie, I . Zhou, X. Wang, T. Liu, L. Deng: *J. Alloys Comp*. Vol 551 (2013), p.677.
- [10] L. Liu, Y. Duan, S. Liu, L. Chen, J. Guo: *J. Magn. Magn. Mater*. Vol 322 (2010), p.1736.
- [11] H. Wang, D. Zhu, W. Zhou, F. Luo: *J. Magn. Magn. Mater*. Vol 375 (2015), p.111.
- [12] Y. Duan, G. Wu, S. Gu, S. Li, G: *Ma. Appl. Surf. Sci*. Vol 258 (2012), p.5746.
- [13] C.L. Yin, J.M. Pan, L.Y. Bai, P. Ding, P.L Yuan: *J. Magn. Magn. Mater*. Vol 340 (2013) , p.65.
- [14] X. Tian, X. D. Liu, H.W. Feng, J. Xu: *Journal of Alloys and Compounds*. Vol 484 (2009), p. 882.
- [15] W.M. Xiao, Y.P. Lei, Z.D. Xia, X. Chen, Y. H and J.K. Nie: *J. Alloys Comp*. Vol 724 (2013), p.24.