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ORIGINAL RESEARCH ARTICLE

Improvement of silicone rubber properties by addition of nano-SiO_2 particles

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ABSTRACT

Aims: To improve the comprehensive performances of a one-part room temperature vulcanized silicone rubber (RTV-1 SiR), Nano-SiO_2 particles are employed as the reinforcing agent.
Materials and methods: The SiO_2/RTV-1 SiR composite is prepared using PDMS, ND42, D-60 and HMDS-modified SiO_2 particles by mixing method. And then, the mechanical and electrical properties, including shear strength, tensile strength, hardness Shore A and volume resistivity, are investigated using experimental method.
Results: The addition of nano-SiO_2 particles can improve the properties of the SiO_2/RTV-1 SiR composite in different degrees. And, the incorporation of 25~30 phr nano-SiO_2 particles is found to be reasonable for silicone rubber composite with the best comprehensive performances.
Conclusions: The significant improvement of mechanical properties and electrical insulation of SiO_2 may be contributed to the addition of modified nano-SiO_2 particles. Additionally, the excellent comprehensive performances of SiO_2/RTV-1 SiR composite guarantee a potential applications as electrical-insulating adhesives.

Keywords: Electrical properties, Mechanical properties, Nano-SiO_2, Silicone rubber

Introduction

Silicone rubber (SiR) is an elastomer material mainly composed of polysiloxane with the structure of R_2SiO. Due to the Si-O bond, SiR shows unique inorganic properties to conventional elastomer materials. The excellent properties, such as heat resistance, chemical stability, low toxicity, electrical insulating, abrasion resistance, optical transparency, weatherability, and ozone resistance, offer the potential for the wide applications in various fields (1).

One-part room temperature vulcanized silicone rubber (RTV-1 SiR), which is one of the most significant types of SiR, has been widely used in electrical-insulating and sealing products. With the rising development of aviation and aerospace technology, researches on RTV-1 SiR adhesives with excellent comprehensive performances have been causing wide range of interest. However, due to the weak inter-molecular interactions between silicone macromolecules, RTV-1 SiR cannot meet the requirements of mechanical strength in the applications of sealing products. Generally, by binary reinforcing agent and modification, the mechanical properties of RTV-1 SiR can be improved in different degrees (2-11). Especially, a great deal of attentions has been paid to the preparation and characterization of the nanocomposites of RTV-1 SiR (5, 8, 12-14). Although much effort has been made, there is still more required to achieve RTV-1 SiR materials with more excellent comprehensive performances followed by greater developing potentialities.

In this paper, our group has carried out experimental processing to obtain a SiO_2/RTV-1 SiR adhesive with significantly improved performance which is mainly attributed to the incorporation of modified nano-SiO_2 particles.

Experimental procedure

Materials

RTV-1 SiR matrix is polydimethylsiloxane (PDMS, viscosity 7500 mPa·s at 25°C, Wacker Chemie). Anilino-methyltriethoxysilane (ND42, Liyang Mingtian Chemical Co.) and titanium complexes (D-60, Hubei Lantian Chemical Co.) are used as a cross-linking agent and a catalytic agent, respectively. The chemical structures of SiR, ND42 and D-60 are shown in Figure 1. Nano-SiO_2 particles (BET-specific surface area 160 ± 25 m^2/g, R8200 series) that are modified by hexamethyldisilazane (HMDS) are supplied by Evonik Degussa GmbH Company.

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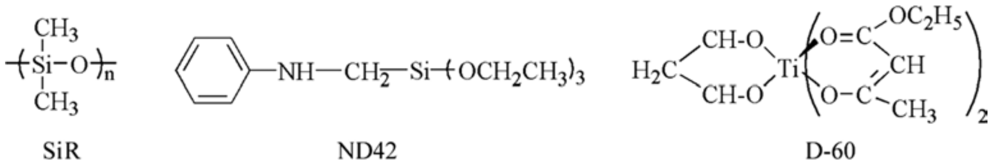

Fig. 1 - Chemical structure of silicone rubber (SiR) ND42 and D-60.

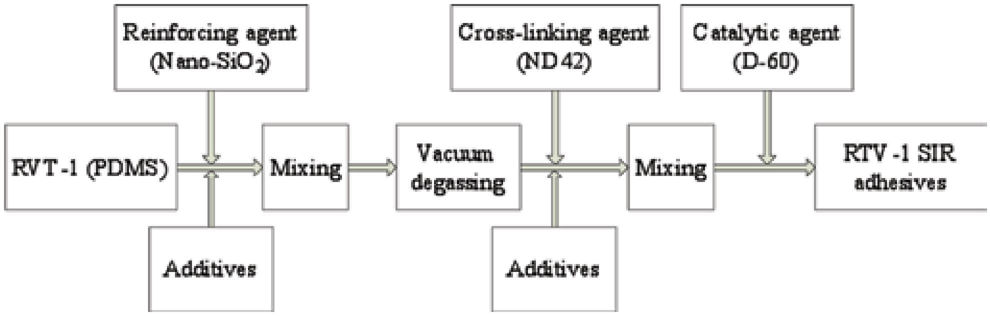

Fig. 2 - Preparation processing of room temperature vulcanized silicone rubber (RTV-1 SiR) adhesive.

Preparation

Preparation of RTV-1 SiR adhesive

In the applications, the curing processing of RTV-1 SiR adhesive is relying on the trace moisture in the air, so the water content should be strictly controlled not only for the precise metering of each component in the system, but also for the overall anhydrous processing of preparation. Figure 2 shows the preparation processing of RTV-1 SiR adhesive. Firstly, the PDMS, additives and reinforcing agent fillers are mixed in a double planetary mixer, during which, the mixing temperature should be lower than 80°C to avoid the case of a gelation reaction in the following steps where the mixture contacts with the additives, cross-linking and catalyst agent, etc. The double planetary mixer is an automatic equipment with temperature and time controls. Then, a continuous degassing by vacuum is processed in the blender, so the small molecules generated in the system are removed. After that, additives and cross-linking agent are added into followed with a mixing and vacuum degassing processing. Lastly, add catalyst agent to the system, stir it for 10 minutes, and then pack the RTV-1 SiR adhesive product in a metal hose. The stir time must be controlled in a reasonable value for a fine mixing of catalyst. After many time tests and comparisons, a stir time of 10 minutes is found to be suitable for a stable performance of adhesives. A shorter stir duration can't achieve a good dispersion of catalyst agent which cause the bad performance of adhesives. However, a longer stir duration at 80°C may cause the curing of adhesives, even failure of experiments.

Preparation of RTV-1 SiR films

The prepared RTV-1 SiR adhesive is extruded from the metal hose and spread on a Teflon sheet uniformly using the Brewer Science® Cee® benchtop spin coater. The surface drying time of adhesive films is usually less than 20 minutes. However, the performance test results show that room temperature curing for at least 7 days is required for adhesive films with the thickness of 2.0 ± 0.1 mm. The mechanical performance of adhesives reaches its maximum value after 7 days of curing, and 80~85% of its maximum value after the first 24 hours of curing.

Preparation of samples for tensile strength testing

The cured RTV-1 SiR adhesive is clipped to dumbbell samples in strict accordance with GB528-82 for tensile strength testing. The total length of samples is 110 mm, and the end width is 25 ± 1 mm. The middle neck area with a length of 33 ± 2 mm and a width of 6 ± 0.4 mm is cut out. Additionally, markings comprising two parallel lines, which don't affect the physical properties of samples, are drawn parallel to the width edge from the center of the sample. The marking lines should be equidistant from the center of the sample. The distance between two lines should be 25.0 ± 0.5 mm.

Preparation of samples for shear strength testing

The samples for shear strength testing are prepared in strict accordance with GB7124-86. LY-12 aluminum alloy is chosen to make the metal sheets which will be bonded by the adhesives (shown in Fig. 3). The metal sheets should have good shape features, with smooth surface and no deformations in terms of bending, skew, burr edges, no rectangular angles, etc. Additionally, metal samples should be cleaned with acetone before bonding.

Mechanical and electrical performance testing

A Testometric M350-20kN electronic testing machine is applied to shear and tensile testing. An XHS type Shore durometer is used for hardness Shore A testing. The resistivity is tested on a ZC43 high resistance and resistivity tester.

Results and discussion

The change of the mechanical properties and volume resistivity of SiO_2/RTV-1 SiR adhesive versus SiO_2 content

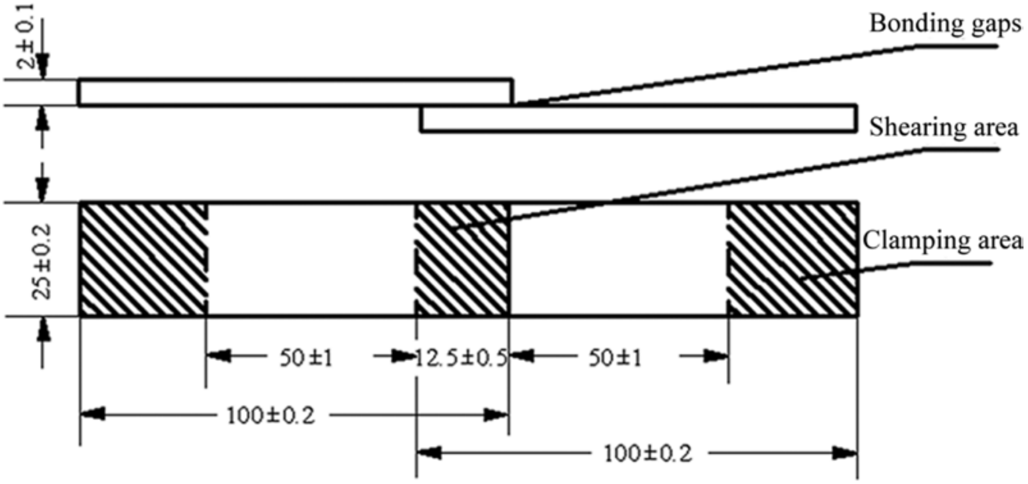

Fig. 3 - Samples for shear strength testing.

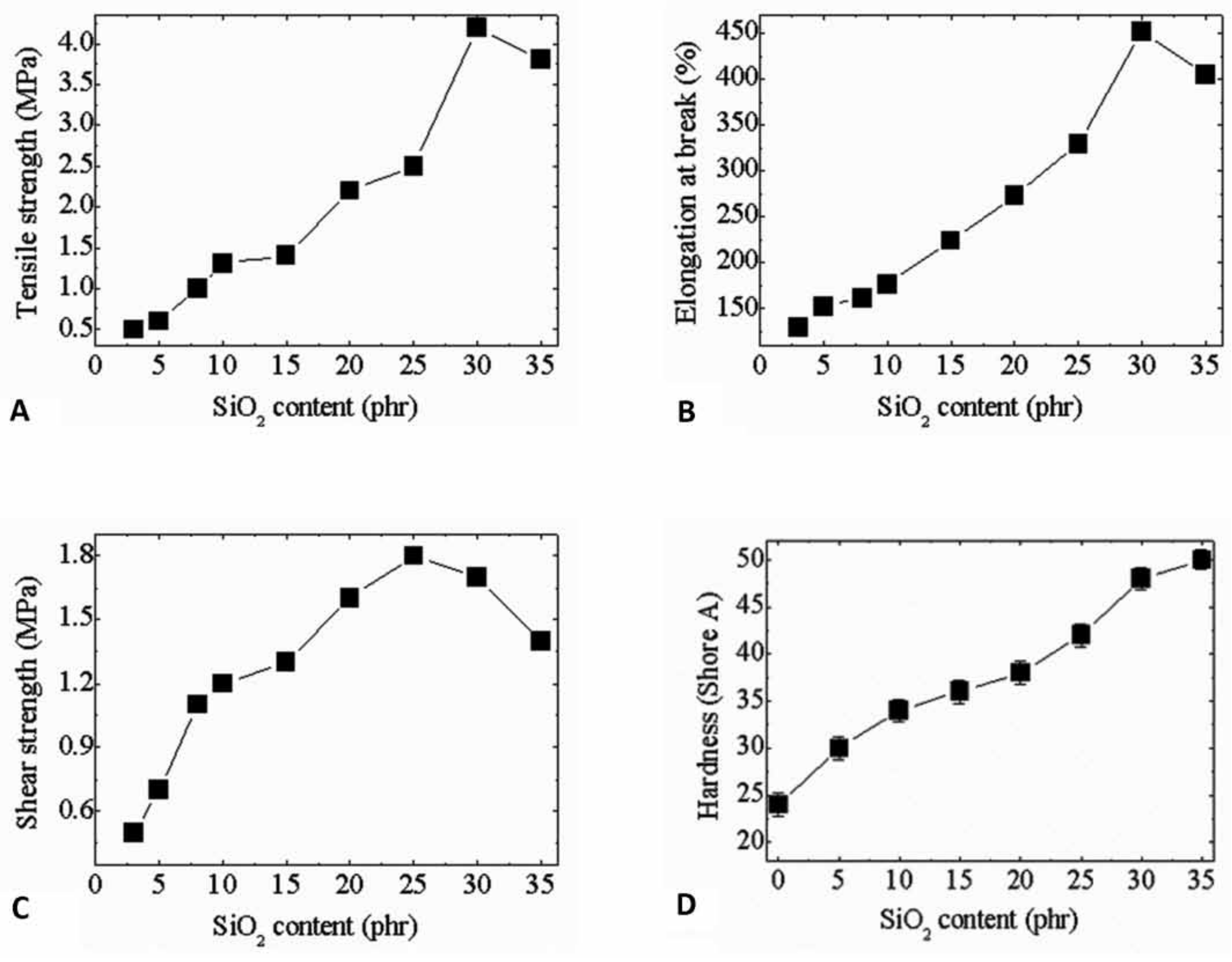

Fig. 4 - Mechanical properties of SiO_2/RTV-1 SiR adhesive versus SiO_2 content. **(A)** Tensile strength; **(B)** Elongation at break; **(C)** Shear strength; **(D)** Hardness Shore A.

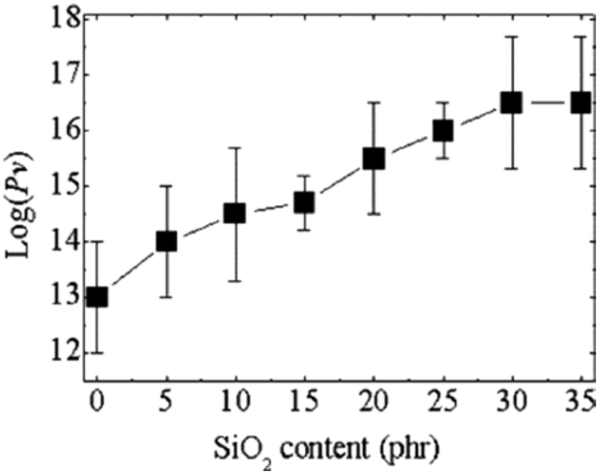

Fig. 5 - Volume resistivity of SiO_2/RTV-1 SiR adhesive versus SiO_2 content.

(phr in wt %) is shown in Figures 4 and 5, respectively. It can be found that the filling of nano-SiO_2 have a significant effect on the mechanical and electrical properties of the adhesive. The tensile strength of the adhesive is increased up to 4.2 MPa and elongation at break to 452% by incorporation of 30 phr nano-SiO_2 particles. The shear strength of the adhesive is increased up to 1.8 MPa by incorporation of 25 phr nano-SiO_2 particles. Additionally, the hardness Shore A and volume resistivity of the adhesive are monotonically increased as the increase of nano-SiO_2 particles filling.

The HMDS treatment of nano-SiO_2 particles may be responsible for the mechanical property enhancement of SiO_2/RTV-1 SiR adhesive: (1) the HMDS treatment improves the linking between the nano-SiO_2 particles and SiR matrix, which results in a significant improvement of the cross-linking degree of SiR, (2) the cross-linking points put extra limits on the movement of molecular chains, (3) the increasing linking intra- and between nano-SiO_2 particles and SiR matrix promote the forms of net structure in matrix. The net structures, as bulk groups, are too rigid to move flexibly. Additionally, the increase of volume resistivity may be a result of an increase of filler content.

Conclusions

Modified nano-SiO_2 particles are used as a secondary reinforcing agent to prepare a SiO_2/RTV-1 SiR. Then, its mechanical and electrical properties, including shear strength, tensile strength, hardness Shore A and volume resistivity, are investigated using experimental method. Experimental testing results show that a reasonable weight filling fraction of nano-SiO_2 particles is 25~30 phr for SiO_2/RTV-1 SiR composite with the best comprehensive performances.

Disclosures

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Conflict of interest: None of the authors has financial interest related to this study to disclose.

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