



MECHANICAL AND THERMAL TRANSPORT PROPERTIES OF AG COMPOSITES: A REVIEW

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ABSTRACT

Silver (Ag) composites are widely studied for their exceptional electrical, thermal, and mechanical performance, making them ideal for applications such as electronics, structural components, and flexible devices. This review provides a detailed theoretical discussion of Ag composites, including polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic composites. Factors influencing mechanical and thermal properties, such as particle dispersion, interfacial bonding, particle size, matrix type, and filler content, are analyzed. Hybrid fillers, multiscale modeling, and temperature-dependent effects are also reviewed. The aim is to guide future research toward high-performance multifunctional Ag composites, emphasizing sustainable synthesis, biocompatibility, and computational modeling.

INTRODUCTION-

Silver (Ag) is highly valued for its superior thermal and electrical conductivity, making it integral in electronics, sensors, and conductive adhesives. Due to cost and ductility limitations, composite approaches are used to combine matrix strength with silver's functional properties (Liu et al., 2021). Ag/polymer, Ag/metal, and Ag/ceramic composites are key for thermal interface materials, flexible electronics, and high-temperature applications (Zhang & Wang, 2021).

1. Types and Fabrication of Ag Composites

1.1 Ag-Polymer Composites

Polymer matrix composites containing Ag nanoparticles or flakes enhance conductivity and mechanical flexibility. Common matrices include polyethylene, polystyrene, NBR, and CPI (Han et al., 2020). Silver improves stiffness, toughness, and heat transport. Fabrication methods like solution mixing, melt blending, and in situ polymerization influence particle dispersion and interfacial adhesion.

1.2 Ag-Metal Matrix Composites (MMCs)

Ag-based MMCs utilize copper, aluminum, or magnesium matrices to combine high thermal conductivity with mechanical strength (Patel et al., 2021). Methods such as powder metallurgy, spark plasma sintering, hot pressing, and additive manufacturing allow control over microstructure, particle orientation, and porosity (Wang et al., 2020).

1.3 Ag-Ceramic Composites

Ceramic matrices including alumina, SiC, and zirconia offer mechanical strength, thermal stability, and corrosion resistance. Ag enhances fracture toughness, thermal conductivity, and electrical performance (Li et al., 2020; Shukla & Jain, 2020). Hot pressing, spark plasma sintering, and infiltration are commonly used fabrication techniques.



2. Mechanical Properties of Ag Composites

2.1 Elastic Modulus and Strength

The elastic modulus and strength of Ag composites increase due to load-bearing silver particles. The effective modulus is influenced by volume fraction, particle orientation, individual phase moduli, and interface bonding (Zhang & Wong, 2019; Zhang et al., 2020).

2.2 Toughness and Fracture Resistance

Silver improves energy dissipation during crack propagation through mechanisms such as bridging and deflection, enhancing fracture resistance in ductile and ceramic matrices (Mishra et al., 2020; Kumar & Singh, 2020).

2.3 Fatigue and Wear Resistance

Under cyclic loading, Ag nanoparticles reduce internal friction and delay crack initiation, improving fatigue life. Their lubricating properties enhance wear resistance, while surface functionalization optimizes tribological performance (Singh et al., 2021; Huang & Chen, 2020).

3. Thermal Transport in Ag Composites

3.1 Thermal Conductivity Models

Silver's high intrinsic thermal conductivity ($\sim 429 \text{ W/m}\cdot\text{K}$) enhances heat transfer. Maxwell's model applies to dilute systems, Effective Medium Theory accounts for interactions at higher filler loadings, and percolation theory explains conductivity through continuous networks at critical concentrations (Maxwell, 1892; Nan et al., 1997; Sharma et al., 2020).

3.2 Influence of Particle Size, Shape, and Distribution



Smaller nanoparticles have larger surface area, improving phonon scattering and interfacial heat transfer. Particle shape can induce anisotropic conductivity. Uniform distribution avoids agglomeration and thermal barriers (Ahmed & Saxena, 2021).

3.3 Interfacial Thermal Resistance

Kapitza resistance at the filler-matrix interface limits heat transfer. Surface modifications or functionalization of Ag particles reduce interfacial resistance, enhancing thermal conductivity (Yu et al., 2016).

4. Parameters Influencing Properties

4.1 Filler Loading and Dispersion

Optimal Ag content enhances mechanical and thermal properties, while excessive loading causes agglomeration and brittleness. Uniform dispersion is crucial for load transfer and heat conduction (Zhao et al., 2019; Javed et al., 2020).

4.2 Interfacial Adhesion

Bond strength between filler and matrix affects mechanical and thermal behavior. Functionalization methods improve adhesion and fatigue resistance (Singh et al., 2021).

4.3 Temperature and Frequency Effects

Material properties vary with temperature and frequency. Elevated temperatures soften polymers, lowering modulus but increasing particle mobility and thermal conductivity. Frequency effects are significant in dynamic applications (Rahman et al., 2020; Li et al., 2021).

5. Recent Theoretical Developments

5.1 Multiscale Modeling

Finite element modeling and molecular dynamics simulations predict nanoscale interactions and macroscopic composite behavior (Xu et al., 2021).



5.2 Hybrid Composites

Combining Ag with CNTs, graphene, or other fillers provides synergistic improvements in thermal, electrical, and mechanical performance (Chatterjee et al., 2021).

5.3 Phase Change and Thermal Interface

Materials Ag composites serve as phase change materials for thermal management, optimizing heat absorption and dissipation through filler content, morphology, and interface engineering (Cho et al., 2020).

6. Applications and Outlook

Ag composites are used in flexible electronics, thermal interface materials, and wear-resistant coatings. Trends include sustainable synthesis, biocompatibility, and computational modeling. AI and machine learning can aid in predicting structure-property relationships and optimizing composite design (Lin et al., 2021; Singh & Pandey, 2021; Roy et al., 2021).

7. Conclusion

Ag composites provide multifunctional advantages, combining thermal, mechanical, and electrical properties. Optimizing particle dispersion, interfacial bonding, and filler geometry is key. Theoretical insights and computational tools will continue to guide the development of advanced Ag composites.

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