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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　　博士（工学）　　氏名　董　凱欣

学 位 論 文 題 名

Study on performance improvement of low working temperature phase change material
(低温作動相変化材料の性能改善に関する研究)

As a promising solution for improving energy efficiency, latent heat storage (LHS) technology has received considerable attention from many researchers. LHS using a phase-change material (PCM) has a high heat storage density and small system size, and PCMs have high stability and low performance degradation because there are only phase-change cycles during the charging and discharging process. PCM has the potential to be used in building material, battery thermal management, solar heat utilization, and industrial exhaust heat recovery. In this study, we focused on low working temperature PCMs (working temperature lower than 200 ℃), try to develop high performance low working temperature PCMs to overcome their drawbacks in practical applications, such as low heat transfer ability, poor durability, leakage, and corrosion problems. These drawbacks would limit the performance of practical heat storage systems in energy charging-releasing speed, system reliability and system cost. By solving these problems of PCMs, the practical application of LHS can be promoted.

Chapter 1 gives the general introduction of this research, introducing the demand for thermal energy storage, the utilization of phase change material and latent heat storage technology, the drawbacks of the PCMs, and the methods of PCM performance improvement.

Chapter 2 reports the development of high thermal conductive sugar alcohol phase change material-based composite enhanced by a new type of carbon fiber sheet material. The practical application of low-temperature latent heat storage systems is limited by the low thermal conductivity of the phase-change material (PCM). We fabricated a phase-change composite (PCC) with high thermal conductivity (k) and a high thermal-conductivity-retention rate (k/k0) during thermal cycles to solve this problem. A new type of high-thermal-conductivity carbon fiber sheet (CFS) material was used to enhance the thermal conductivity of erythritol PCM. CFSs were stacked and compressed to form a network structure of high thermal conductivity carbon fiber, then the porous structure was impregnated with liquid erythritol PCM in a vacuum. The thermal conductivity of the PCC was measured by using the laser flash method, and the microstructures were analysed by energy dispersive spectroscopy using a scanning electron microscope. Durability tests of 5 and 100 cycles, using differently shaped PCC samples, were conducted to investigate the thermal conductivity of the PCC. With the addition of 14.8 volume percent CFS, the thermal conductivity of the PCC was improved to 24.4 W·m-1·K-1 (32.4 times higher than that of a pure PCM), and the thermal conductivity retention rate after 100 thermal cycles reached 89.4 percent. High-thermal-conductivity carbon fiber network structures with high connectivity were established in the PCC before the durability test and after 100 thermal cycles. The fabricated PCC exhibited a high thermal conductivity with less enhancement material and prolonged durability.

Chapter 3 introduces the development of a paraffin wax based, anisotropic high thermal conductive form stable phase change composite. To address the drawback of low thermal conductivity of conventional paraffin-wax PCM for thermal management utilizations, a phase change composite (PCC) was assembled via a vacuum impregnation method, using a carbon fiber network material as the supporting matrix. The sheet-shaped carbon fiber material was stacked and compressed, and then impregnated with the liquid paraffin wax PCM to form the composite. The thermal conductivity, durability, shape stability, chemical stability, and heat storage characteristics of the PCC specimen were carefully analysed. The maximum thermal conductivity of the PCC was 11.68 W·m-1·K-1 (46.7 times compared to that of pure paraffin) in the horizontal direction, and 0.93 W·m-1·K-1 in the vertical direction of the sample, with 17.44 volume percent CFS added. The thermal conductivity retention rate after 200 thermal cycles was 78.6 percent. The PCC also displayed good stability in terms of chemical structure, shape, and heat storage ability. This study offers insights and a possible strategy for the development of anisotropic high-thermal-conductivity PCCs for potential applications in latent heat storage systems.

Chapter 4 introduces an optimized fabrication method of long durable microencapsulated metal-based phase change material. PCM for thermal management applications is required to have high thermal conductivity, no leakage, and high heat storage density in volume. Gallium has been considered as a good PCM because of its high heat transfer ability and heat storage density. To address the issues of metal corrosion and leakage, a microencapsulation method, through which a stable corrosion-resistant ceramic shell can be formed from the liquid metal, is proposed. In this study, an optimized fabrication method for a microencapsulated phase change material (MEPCM) consisting of liquid-state Ga droplets, possessing high durability and heat storage density, is presented. A fabrication route comprising particle formation, hydrothermal treatment, and calcination is proposed. In particular, the thickness and crystal size of the GaOOH shell are controlled by changing the pH during hydrothermal treatment to produce a highly durable shell. The morphology and microstructure, phase composition, heat storage capacity, and durability of the prepared Ga-MEPCM are investigated. In addition, treatment conditions and the shell formation mechanism are analyzed. The results show that pH 9 is the most suitable shell-forming condition, at which the thickest Ga2O3 shell with the smallest crystal size can be produced, which is beneficial for ensuring durability. The MEPCM achieved 200 cycles without leakage with a high heat storage density of 369.4 J·cm–3.

Chapter 5 summarized the conclusions of the conducted studies.