CORROSION TESTS ON METAL - PHASE CHANGE MATERIAL PAIRS USED FOR THERMAL ENERGY STORAGE

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Abstract

Phase change materials (PCMs) are now a well-established category of materials for thermal energy storage. Most PCMs need to be hermetically sealed in a container or a storage tank because of the risk of leakage to the surrounding environment when a PCM is in the liquid state. A good compatibility between the PCMs and the materials for their encapsulation is very important for the long lifespan and safety of the heat storage systems. Metals are excellent heat conductors and for this reason they are often used as encapsulation materials for PCMs. The present paper focuses on the methodology and results of the compatibility tests of organic and inorganic PCMs with metals. Three sets of metallic samples of encapsulation materials have been prepared. The first set contained copper samples, the second aluminum samples and the third stainless steel samples. The samples were immersed in the PCMs creating metal - PCM pairs and then subjected to periodical heating and cooling in a small environmental chamber, which imitated the operation of thermal energy storage. One set of metal samples was withdrawn for testing each month. The results indicate a good compatibility between stainless steel and all tested PCMs.

Keywords: Corrosion, metals, phase change materials, material compatibility

1. INTRODUCTION

High thermal conductivity is typical for all common metals used in practice and thus metals are materials of choice when good heat conduction is needed. One of the examples of their use is encapsulation of latent heat storage media. These media utilize phase change transition during melting and solidification and thus absorb and release higher amount of thermal energy in comparison with sensible heat storage media, e.g. rock, gravel or water. Because latent heat storage media change phase from solid to liquid and vice versa, they must be hermetically encapsulated to avoid the risk of leakage to the surrounding environment. Thermal energy storage is important for overcoming the mismatch between energy needs and energy supply from renewable energy sources, e.g. solar thermal or biomass boilers. Thermal energy is often stored in tanks or boreholes in such energy systems. In the built environment, thermal energy can be stored directly in the building structures when solar heat gains through the external windows are available. The development of suitable latent heat storage media encapsulated in proper and durable materials with high thermal conductivity is a key issue for the consequent development of latent heat storage technology. Added value of latent heat storage technology is the significant reduction of the volume of heat storage material due to its high thermal energy storage density. Latent heat storage media for the use in hydronic heating and cooling systems are usually sealed in metal containers, tubes or spheres [1]. The same metal materials are often used for heat exchangers, because the latent heat storage medium must be separated from the heat transfer fluid. Latent heat storage media represented by Phase Change Materials (PCMs) can be organic or inorganic. The compatibility between the storage medium and the encapsulating material has a significant impact on the stability and service life of the whole thermal energy storage system. Khan et al. [2] collected results from experimental works focusing on the compatibility between the heat storage media and the container materials. Authors concluded that salt hydrates caused corrosion of metal containers with the exception of stainless steel, which showed a good compatibility.

In this study, selected metals were tested experimentally to find the most suitable material for encapsulation of PCMs. The chemical compatibility of the PCMs and selected metals was analyzed by immersion corrosion tests.

2. MATERIALS AND METHODOLOGY

Three metals were selected for testing of their compatibility with PCMs. The chosen materials differed in their expected chemical resistance. The first material was aluminum AW 1050 H111. Excellent electrical and heat conductivity is its important characteristic for which it is widely used in many applications. Aluminum is often used for macro-encapsulation of PCMs because it provides high ratio between the weight of a PCM and the weight of the container. The second material selected for testing was copper CW024A, which also has good electrical and heat conductivity. Corrosion on the surface of copper occurs due to weather and it has a typical color. The third tested metal was stainless steel EQ308L, which was chosen for its high resistance to chemical corrosion. It was assumed that stainless steel would show the smallest visual change, weight change and the rate of corrosion during the experiment. All samples were of a rectangular shape with the surface area of about 7.0 cm^2 in case of aluminum, 7.5 cm^2 in case of copper and 9 cm^2 in case of stainless steel.

Two organic PCMs and one inorganic PCM were used in the compatibility tests. Hydrated salts are a basic component of many PCMs in the inorganic category and they are known for their corrosive behavior. A large group of organic PCMs is based on paraffin. Two commercially available paraffin-based PCMs Linpar 17 (phase change temperature of 21 °C) and Linpar 1820 (phase change temperature of 27 °C) were chosen as the representatives of organic PCMs and Rubitherm SP25 (phase change temperature of 25 °C) represented inorganic PCMs in the tests. This inorganic PCM had neutral pH. The metal samples were immersed in the beakers filled with the PCMs and the beakers with the samples were put into a small environmental chamber. The thermal test cycle consisted of four stages. In the first stage, the temperature in the chamber was slowly increased to 40 °C. In the second stage, the temperature in the chamber was maintained constant at 40 °C. In the third stage the temperature was slowly decreased to 15 °C and in the fourth stage it was maintained at 15 °C. Each stage lasted 4 hours and the cycle was repeated for 4 months. One set of metal samples was withdrawn for testing each month. The procedure for evaluation of the corrosion rate CR of metal samples, as described in [3, 4], was used. Preparation, cleaning and evaluation of the samples was done in accordance with ASTM G1 standard presented in [5]. Upon withdrawal from the chamber, the samples were cleaned, visually inspected, weighted and the corrosion rate was calculated according to the following equation:

$$CR = \frac{m(t_0) - m(t)}{A \cdot (t_0 - t)} \qquad (1)$$

Where *CR is the* corrosion rate ($mg \cdot cm^{-2} \cdot a^{-1}$), $m(t_0)$ is the initial mass (mg), $m(t)$ is the final mass (mg), A is the area of the metal sample (cm^2) and (t_0 - t) is exposure time (year).

3. RESULTS AND DISCUSSION

The main goal of the study was to investigate the suitability of selected metals for their employment as encapsulation materials for PCMs. The suitability was explored in terms of visual changes and weight changes after exposure to PCMs. It was assumed that the exposure of metal samples to the PCMs would affect their shape, form, and perhaps also color. This assumption proved true in case of the samples of copper immersed in Rubitherm SP25. The copper samples exhibited surface non-uniform corrosion after being exposed to PCM for more than 1 month.

Figure 1 shows the set of copper samples with the progressing surface corrosion in the order of their withdrawal from the chamber. The sample number 8 was withdrawn from Rubitherm SP25 after about 104 days, corrosion having covered about 40% of its surface. The aluminum samples have also shown signs of surface corrosion in Rubitherm SP25, having been covered in a white powder. This outcome has not been observed in other PCMs and the samples of stainless steel. In terms of the visual changes the copper samples exposed to Rubitherm SP25, which appeared to be the most corrosive, have been negatively affected.

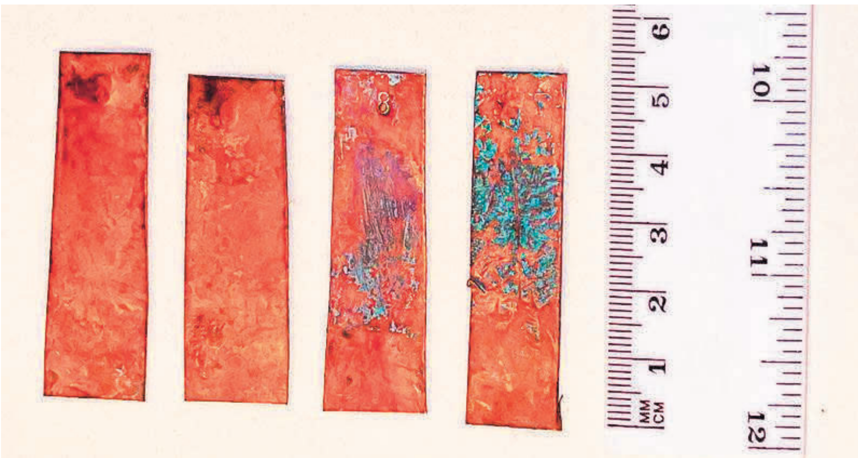

Figure 1 Visual changes of copper samples immersed in Rubitherm SP25 depending on the exposure time (from left to right: 1 month - 2 months - 3 months - 4 months)

The samples of all metals showed very small corrosion rates throughout the duration of their exposure to the two types of paraffin-based group PCMs (Linpar), as can be seen in **Figure 2** and **Figure 3**. The corrosion rates were almost negligible. The corrosion rates have likely been affected by the measurement error and surface cleaning of the metal samples. The dependence of the weight change of tested metals on the exposure time is presented in **Figure 4**.

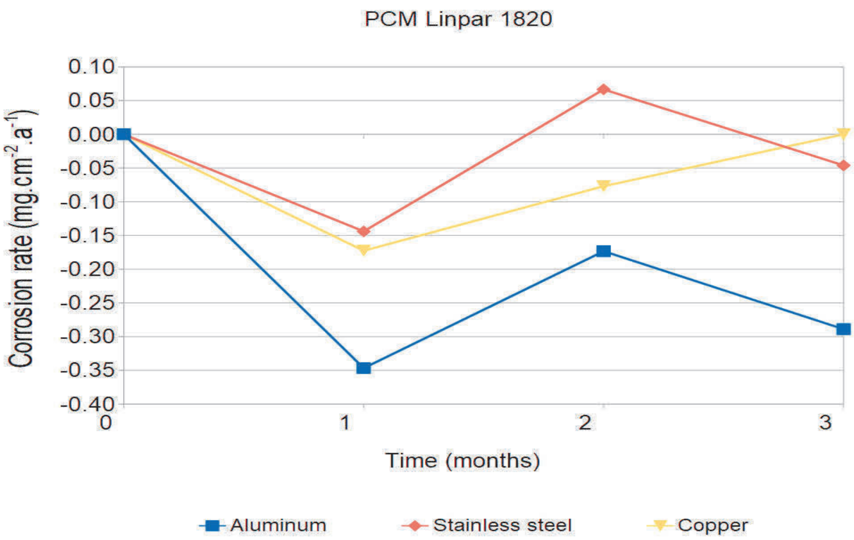

Figure 2 The dependence of corrosion rate CR (%) on exposure time for Linpar 1820

The behavior of the copper samples exposed to Rubitherm SP25 was different from other two metals, as can be seen in **Figure 3**. This behavior was accompanied by the occurrence of surface corrosion on the samples. The aluminum and stainless steel samples have shown only slight changes on the surface during the tests and it can be recommended to repeat the test for longer time periods. The largest mass loss of copper immersed in salt-hydrate based inorganic PCM represented by Rubitherm SP25 corresponds with the results presented by Farrell *et al.* [6].

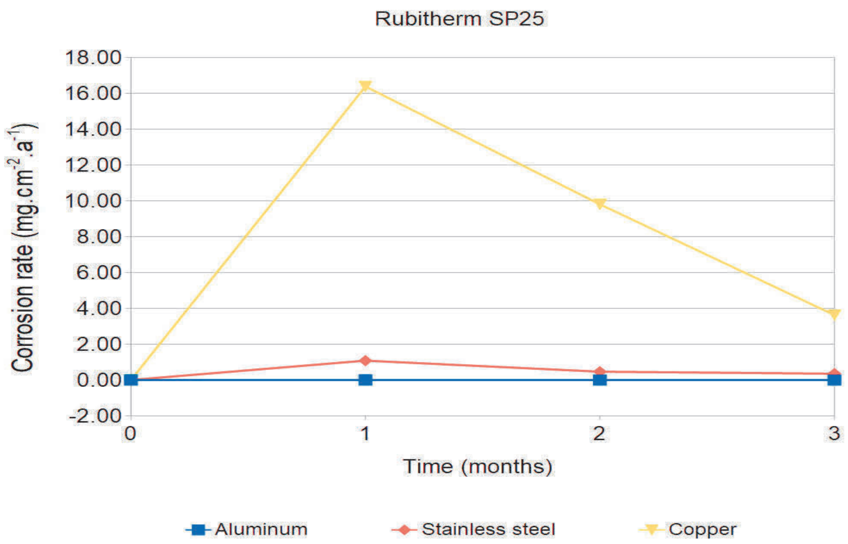

Figure 3 The dependence of corrosion rate CR (%) on exposure time for Rubitherm SP25

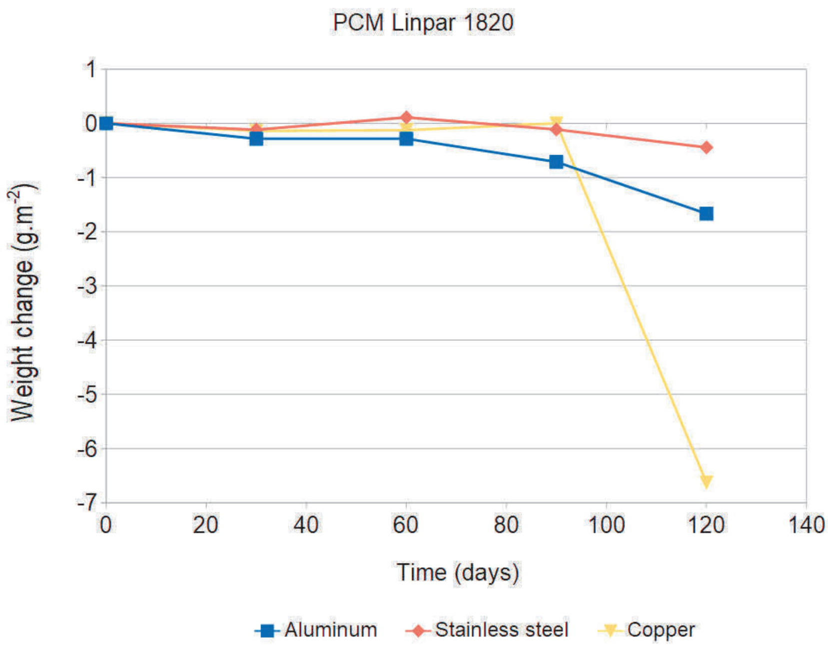

Figure 4 The dependence of weight change on exposure time for Linpar 18-20

4. CONCLUSION

The conducted testing confirmed good chemical compatibility between stainless steel and the three selected PCMs. The highest corrosion rate was obtained for copper immersed in a salt-hydrate based PCM. All three tested metals immersed in organic PCMs exhibited almost no weight change. Therefore, there is no need for special coating when these metals are in direct contact with the organic PCMs. Based on the presented results copper is not a suitable material for encapsulation of inorganic PCMs containing hydrated salts.

ACKNOWLEDGEMENTS

This work was supported by the Czech Science Foundation under project No. 18-19617S "Hysteresis of the temperature-enthalpy curve during partial phase change of latent heat storage materials".

REFERENCES

[1] OSTRY, Milan and CHARVAT, Pavel. Materials for advanced heat storage in buildings. *Procedia Engineering*. 2013. vol. 57, pp. 837-843.

[2] KHAN, Zakir, KHAN, Zulfiqar and GHAFOOR, Abdul. A review of performance enhancement of PCM based latent heat storage system within the context of materials, thermal stability and compatibility. *Energy Conversation and Management*. 2016. vol. 115, pp. 132-158.

[3] CABEZA, Luisa, F., ROCA, J., NOGUÉS, M., MEHLING, H. and HIEBLER, S. Immersion corrosion tests on metal-salt hydrate pairs used for latent heat storage in the 48 to 58 °C temperature range. *Materials and Corrosion*. 2002. vol. 53, pp. 902-907.

[4] MORENO, Pere, MIRÓ, Laila, SOLÉ, Aran, BARRENECHE, Camila, SOLÉ, Cristian, MARTORELL, Ingrid and CABEZA, Luisa F. Corrosion of metal and metal alloy containers in contact with phase change materials (PCM) for potential heating and cooling applications. *Applied Energy*. 2014. vol. 125, pp. 238-245.

[5] KAHWAJI, Samer, JOHNSON, Michel B., KHEIRABADI, Ali. C., GROULX, Dominic, WHITE, Mary Anne. Fatty acids and related phase change materials for reliable thermal energy storage at moderate temperatures. *Solar Energy Materials and Solar Cells*. 2017. vol. 167. pp. 109-120.

[6] FARRELL, Anthony J., NORTON, Brian and KENNEDY, David M. Corrosive effect of salty hydrate phase change materials used with aluminum and copper. *Journal of Materials Processing Technology*. 2006. vol. 175, pp. 198-205.