

Abstract

This thesis presents the subsequent design and fabrication steps of cast heat enhancers (referred as inserts) for use in thermal energy storage (TES) systems based on corrosive phase change materials (PCM).

Thermal energy storage is becoming more and more widely used worldwide. Solar energy and waste energy from industrial processes are utilized for this purpose. One of the most popular methods of thermal energy storage involves the use of PCM (e.g. salts, their hydrates, paraffins), which store energy in the form of latent heat (during phase transition). PCMs have high enthalpy of phase transition, but their disadvantages include low thermal conductivity and high corrosivity - especially in the case of salts and their hydrates. In order to improve thermal conductivity, cast metal inserts can be used along with protective anti-corrosion coatings.

Various insert geometries were analysed through numerical simulations using FLOW-3D software to optimize their structure for enhanced heat transfer within the TES unit. Based on the literature review, different sets of shapes based on biomimetic designs were proposed: snowflake, tree, tree on stand. These shapes were subjected to numerical tests for different TES arrangements, where the heat source was either from the centre of the structure (channel for heat transfer fluid - HTF), from the bottom of the vessel, or from the outside (side walls of the vessel, structure placed in a macrocapsule). Based on the results obtained, it was determined that the use of an extended shape geometry was important for all the structures studied. Adjusting the length and number of branches of the structure's arms has a direct effect on the melting rate of the deposit (charging of the unit) and also reduces the temperature gradient in the deposit.

In the next stage, three aluminium alloys were tested for the manufacture of thin-walled structures to improve thermal conductivity. For this purpose, the investment casting technique was employed. Three aluminium alloys were selected for comparison: EN AC-44200 (AlSi12), EN AC-42100 (AlSi7), EN AW-5754 (AlMg3). Initial casting tests were carried out on sheets with a wall thickness of 2 mm, and in a next stage, tree-based inserts were cast. The patterns were made using fused deposition modelling (FDM) technology, which left a characteristic wavy structure inside the mould after dewaxing (burnout). Appropriate selection of casting parameters allowed the texture of the pattern to be reproduced accurately. Macro- and micro-shrinkage phenomena were observed on the surface of the castings, which could be eliminated by adjusting the casting temperature and the amount of metal fed into the mould. In the end,

good quality castings were obtained from all the proposed alloys, but the best results were achieved for the AlMg3 alloy, which is usually used for welding and bending.

The plasma electrolytic oxidation (PEO) technique was proposed as a method to prevent corrosion of aluminium heat exchangers in corrosive PCM environment. Samples of EN AC-44200 alloy were subjected to the PEO process in two electrolyte solutions, sodium-silicate-potassium and sodium-silicate-phosphate, and then the samples were tested in $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ hydrate, maintaining them in a molten PCM environment (after oxidation in the sodium-silicate-potassium electrolyte) and a cyclic loading test by melting and free cooling the PCM (after oxidation in the sodium-silicate-phosphate electrolyte). The weight change of the samples was investigated, and SEM and EDS observations and XRD tests were made to determine possible changes. Untreated cast samples showed signs of corrosion and slight mass variation, whereas PEO-treated samples exhibited no mass change or visible degradation, confirming the coating's protective effectiveness. To assess whether the PEO coating negatively affected thermal conductivity, a series of charging and discharging cycles were performed on a laboratory scale TES unit filled with a PCM based on nitrate salts using both coated and uncoated inserts. The tests proved that PEO coatings have no negative effect on the heating and cooling performance of the system, as the temperature curves obtained for coated and uncoated inserts are comparable.