A study of the behaviour of mortar-based electrical cells

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ABSTRACT:*The purposes of this study are (i) to determine the optimal mortar mixture ratio for a mortar electrolyte, (ii) to study the internal structure of mortar samples using a microscope at the department of Material Science, and (iii) to study the behaviour or electrical properties of mortar-based electrical cells.The research methodology starts with finding the optimal mixture ratio of the Portland cement, fine sand, rock salt, and water to form 1.79 kg of mortar as well as evaluating an electricity supply abilityfor different mixture ratios. Then, the internal structure of mortar with the chemical formula 2CaOSiO2 + NaCl + SiO2is viewed under a 1000x magnification microscope. Finally,two test cases are performed to study the behaviour of mortar-based cells: the case with water and without water added to mortar-based cells. The results show that (i) the mortar sample with the optimal mixture ratio could deliver the maximum electrical power of 0.000752mW, (ii) the microscopicallywhite salt crystals were spotted in the porous texture of the mortar sample, and (iii)the mortar-based cells, electrically connected in series in the testcase without and with water added to the mortar,could provide maximum electrical power of 350 and 290 mW, respectively, to a resistive load for 3 minutes.*

KEYWORDS: *mortar-based electrical cells, mortar, internal structure, behaviour, the Portland cement*

I. INTRODUCTION

Research and development in alternative electricity sources has been continuously carried out so far. Solid polymer electrolytes were developed from sulfuric acid in salt solution ionically bonded with cathode and anode plates; these solid electrolytes can store more energy, absorb energy faster, and have longer life expectancy than other chemicals. Bin Li and et al.proposed a new electrolyte capable of creating a solid bond between the cathode and anode of LiMn2O4/Graphite batteries; the electrolyte also improved lithium-ion circulation in LiMn2O4/Graphite batterieswith carbonate electrodes using prop-1-ene-1,3-sultone (PES) as an additiveat higher temperature. The cyclic performance of LiMn2O4/Graphite cells using the developed electrodes at 60 °C was evaluated by constant-current charging and discharging tests. In comparison with electrodes using vinylene carbonate (VC) as an additive, the developed electrode had superior circulation ability and dimensional stabilityat higher temperature.The ability to maintain Graphite helped prevent electrolytedecomposition effectively. The study in ceramic and polymer solid electrolytes for lithium-ion batteries by Jeffrey W. Fergus found that lithium-ion batteries play an important role in energy storage in various applications, including electronic devices, transportation, and large-scale energy sources. The performance of lithium-ion batteries depends on constituent materials, especially an electrolyte. Solid electrolytes have the advantage of design simplicity and safety in working operation.

However, they have less electrical conductivity than organic liquid electrolytes. From above literature, this research studiesthe behaviour of cement electrolytes. The Portland cement used consists of Tricium Silicate (C3S), Dicalcium Silicate (C2S), Trichalcium Luminate (C3A), and TetralciumMoluminoferrite (C4AF):theirchemical compositions are C3S = CaO - SiO2 -Al2O3 -Fe2O3 --SO3, C2S = SiO2 - C2S, C3A = Al2O3 – Fe2O3, C4AF = Fe2O3, respectively.When the Portland cement is mixed with sand and water, the C3Sgenerate 500 J/g of heat, the C2S generates 250 J/g of heat, the C3A generates up to 850 J/g of heat, and the C4AF generates 400 J/g of heat. If a positively-charged metal and a negatively-charged metal are placed between a piece ofa cement sample, the DC current flows from the positive electrode to the negative one, through the cement.This result is consistent with the research on electrical and thermal properties of mortar that contains recycled metallic residues by J. Norambuena-Contreras and et al.The research studied cement during a hydration reaction. The internal heat is generated when both positive and negative electrodes are in contact with cement.

Then, 0.868 and 0.796 m-1K1 of heat aretransferred tothe positive and negative electrode, respectively, causing different potential across both electrodes.Following the mentioned research, this study focuses on electricity generation from mortarusing ionic bonds [4]. There are several ways to combine atoms such as a covalent bond and an ionic bond, to name a few. In a covalent bond, electrons are shared between atoms to gain stability.Unlike a covalent bond, electrons are transferred between atoms to create oppositely charged ions in an ionic bond, namely one atom loses electrons the other gains electrons. The electrostatic force attracting oppositely charged ions combines atoms together. An ionic bond is formedbetween metal and non-metal. In the process, metal loses electrons in the outermost shell, creating a cation. Meanwhile, non-metal gains electrons to fill their outermost shell, creating an anion. In this study, the internal structure of cementis studied by a microscope from the department of Material Science. The electrical properties are studied using LEDs as an electrical load with brightness representing an amount of electric current, and using a resistor to determine electric power and the relationship between voltage and current. Electricity generation from cement is an innovation in Energy sector for Thailand. In addition, this study is a guideline to the invention of construction materials with energy source capability.

II. OBJECTIVES

1. Determine the optimal mortar mixture ratiofor mortar-based electrical cells.
2. Study the internal structure of a mortar sample by using a microscope at the department of Material Science.
3. Study the behaviour of mortar-based electrical cells.

III. RESEARCH METHODOLOGY

1.Study the mortar mixture ratio of the Portland cement, fine sand, and rock salt. The total mass ofa piece of a mortar sample is 1.79 kg. Different mixture ratios are shown in Table 1.

Table 1: Mortar mixture ratios.

Formula	The Portland cement (g)	Fine sand (g)	Rock sault (g)	Water (g)	Results		
					Voltage (mV)	Current (uA)	Power (mW)
1	448	896	224	448	0.261	0.00	0.00
2	448	1120	224	448	0.752	0.001	0.000752
3	448	672	448	448	0.267	0.00	0.00
4	448	1344	224	448	0.301	0.00	0.00

This test is aimed to determine the optimal mixture for mortar-based electrical cells.After mixing all ingredients, the mixture was left in a mould for 60 minutes, during which ionic bonds gradually form and the mixture becomes solid. Then, a 10-**Ω** resistor is connected to the mortar-based cell or the mortar sample as shown in Fig. 1.It is found that only Formula 2 in Table 1 gaveelectrical power that satisfies the criterion.

Fig. 1: Formula 2 mortar with a resistive load

After the mortar sample was mixed and left for one week, the mortar-based cell could supply up to 107 mW to a resistive load as shown in Fig. 2.

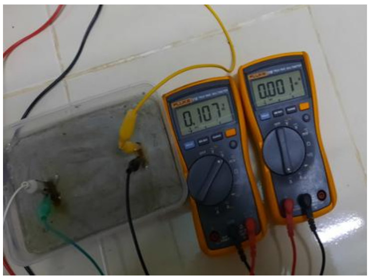


Fig. 2: Electricity supply test for the mortar-based cell connected to a resistor

2. The mortar sample was initially formed by the hydration of cement. Then, it became a gel-like substance or cement gel. After it was hardened, the structure was uneven and porous. This process depends on time for the formation of cement paste, temperature at which a hydration reaction occurs, and a water-to-cement ratio with the chemical composition containing calcium, silicate, and hydrate.

According to the above explanation, the microscopic structure of the mortar sample at point a, b, and c was uneven and porous. Unlike point a and b, the structure at point c had the white salt crystals from the reaction between calcium and silicate.

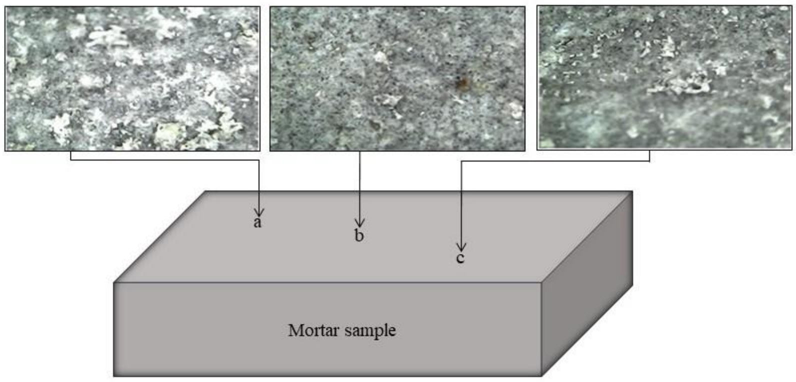


Fig. 3:The internal structure of the mortar sample

3.Astudy of the behaviour of mortar-based electrical cells or solid electrolytes.A solid electrolyte is a certain type of polymer that allows ions to pass through, except electrons. Also, it can be fitted with a positive electrode (cathode)TiS2 electrode (anode) and to form a battery cell. The redox reaction occurred in the cell is as follows.

At a positive electrode: Li ------> Li + (s) + e-

At TiS2: Cathode+ e- -----> TiS2 - (s)

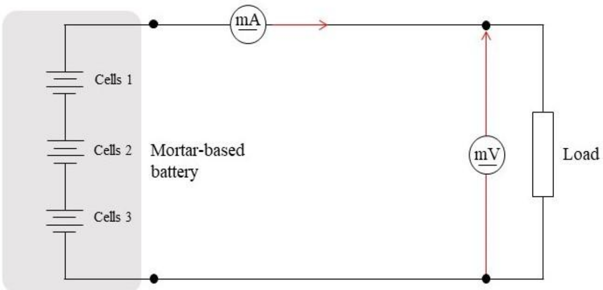
The overall reaction: Li(s) + TiS2(s) ----> Li +(s)+ TiS2 -(s)

The cell potential is 2 V approximately. When lithium loses an electron, it becomes Li+. This L+ passes a solid electrolyte to the cathode. Meanwhile, TiS2gains an electron and becomes TiS2-. Finally, the LiTiS2 solid electrolyte is formed from TiS2- and Li+.Due to its electron insulation of this electrolyte, this electrical cell can be used without short circuit. The above principle leads tothe idea of using mortar as a solid electrolyte with a copper anode and a zinc cathode.The chemical formula is 2CaOSiO2 + NaCl. + SiO2 + Water + Cu + Zn = DC

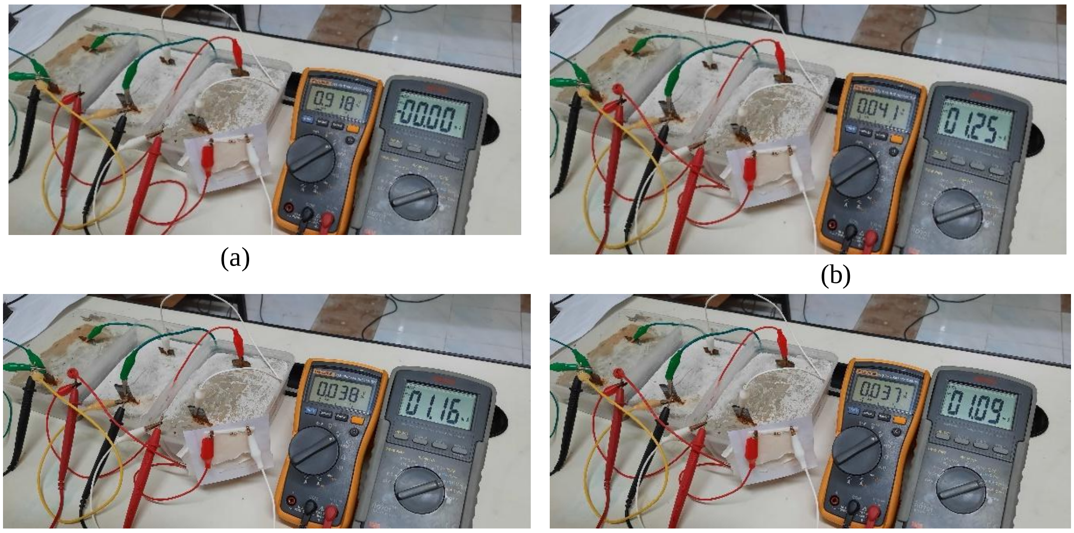
An ionic bond is electrostatic attraction between positive and negative ions which are created by electron transfer between atoms.This bond is generally formed between metal and non-metal and its compound is called "ionic compound".As mentioned earlier, metal loses electrons in the outermost shell, creating a cation; and non-metal gains electrons to fill the outermost shell, creating an anion.According to the principle of ionic bonds, mortar as a solid electrolyte has high salt concentration if humidity in the mortar is greater than 2%. The movement of ions gives rise to electric potential difference and electric current in the mortar.A number of mortar pieces can be electrically connected in series and parallel to create a mortar-based battery; in addition, its behaviourcan be analysed by measuring total output voltage, current, and power. The chemical formula for the mortar-based electrical cell is

$$2CaO \cdot SiO_2+CaO+MgSO_4+SiO_2+water \rightarrow mortar+Cu+Zn = DC.$$

3.1The mortar sample test without water. The formation of ionic bonds was tested using a 76.20 x 50.80 mm. copper plate and a 76.20 x 50.80 mm. zinc plate. The mortar-based cells or battery without water added to the mortar supplied electricity to a 10-Ω resistor as shown in Fig. 4.



The equivalent circuit in the resistive load test



(a) (b)

(c) (d)

Fig. 4:The mortar test without water

In the test, the mortar-based battery, which contains 3 pieces of mortar connected in series without water, continuously supplied electricity toa 10-Ω resistor for 3 minutes. The output voltage and current of the mortar-based battery were measured and shown in Fig. 5.

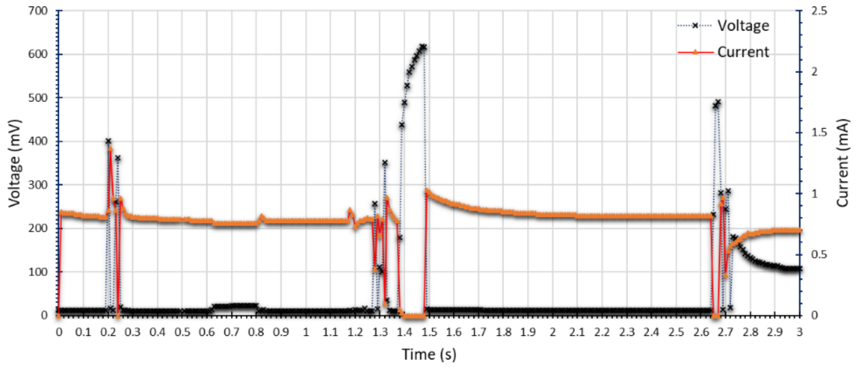


Fig. 5: The mortar-based battery's voltage and current vs time inthe test case without water

Fig. 5 shows that the maximum supply voltage was616mV and the maximum current was 1.37 mA.The average voltage and current was 54.61 mV and 0.759 mA, respectively.

3.2 The mortar sample test with water. The formation of ionic bonds was tested using a 76.20 x 50.80 mm. copper plate and a 76.20 x 50.80 mm. zinc plate. The mortar-based cells or battery with water added to the mortar supplied electricity to a 10-Ω resistor as shown in Fig. 6.

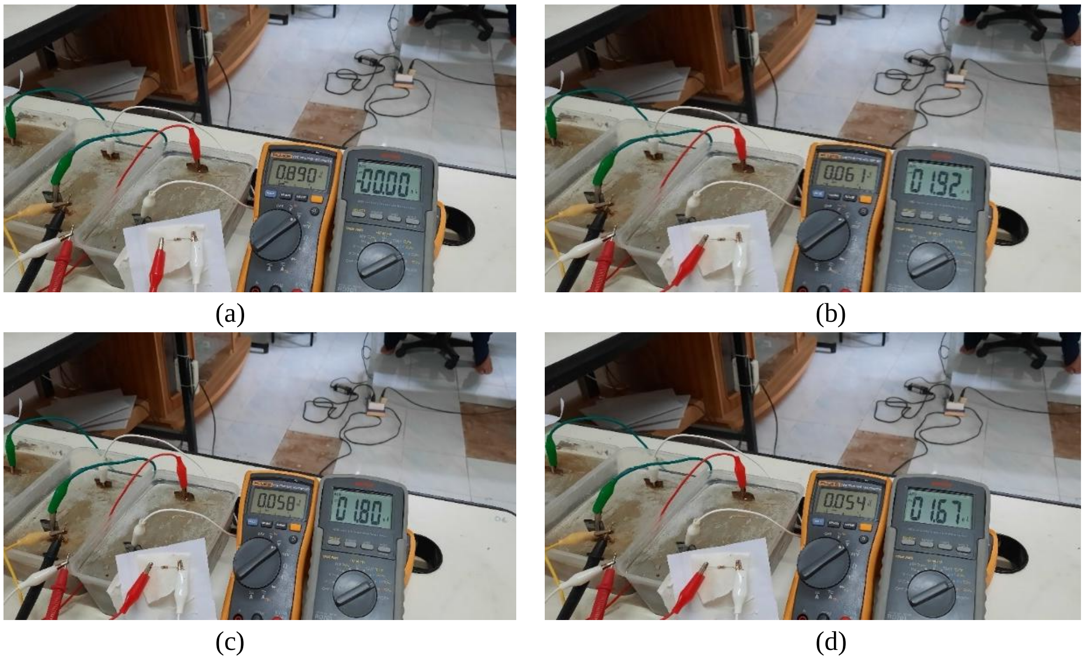


Fig. 6: The mortar test with water

In the test, the mortar-based battery, which contains 3 pieces of mortar connected in series with water added to all three mortar samples, continuously supplied electricity to a 10-Ω resistor for 3 minutes. Fig. 6 (a)-(d)

IV. RESULTS AND DISCUSSION

The results of the data analysis are presented in Figure 7. Show the output voltage and current of the mortar-based battery.The maximum supply voltage was21mV and the maximum current supplied to a resistor was 1.92 mA. The average voltage and current was 19.203 mV and 1.309 mA, respectively.

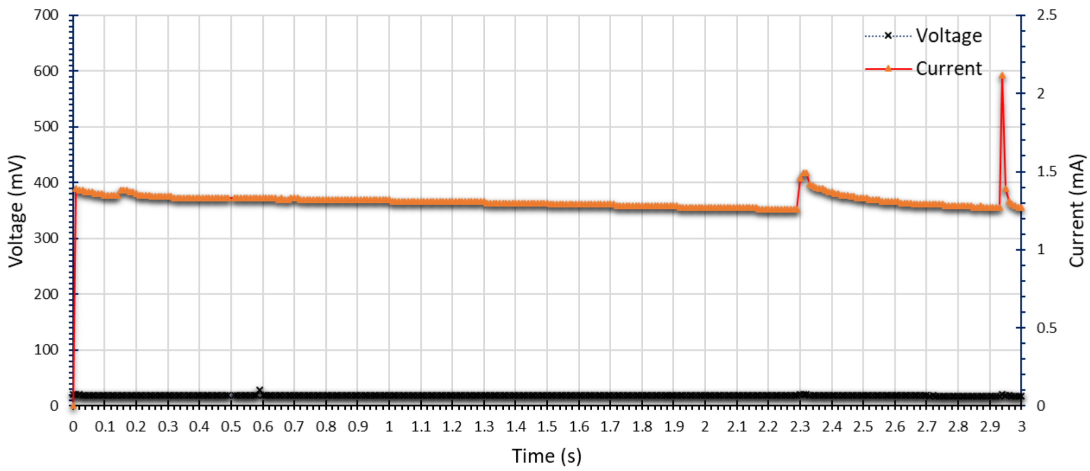


Fig. 7: The mortar-based battery's voltage and current vs time in the test case with water

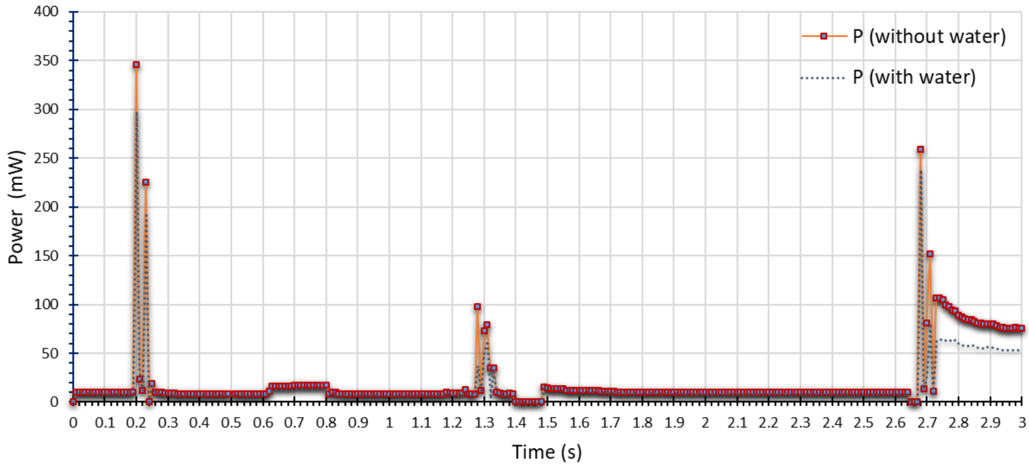


Fig. 8:Power comparison between the test case with and without water added to the mortar

Fig. 8 shows the electric power supplied to a resistor for the test case without water and with water added to the mortar samples being tested. The average power was 21.192 mW and 15.858 mW, respectively. The results also show that the mortar-based cell without water or dry cell could deliver more power to a resistive load 5.334 mW greater than the power from the wet cell – because the internal resistance of the dry cell is less than that of the wet cell.

V. CONCLUSION

A study of the behaviour of a mortar-based solid electrolyte cell. In the test case without water, 3 pieces of mortar sampleswere electrically connected in series and supplied electricity to a 10-Ω resistor for 3 minutes. The results show that the maximum output voltage was 0.918 V and the maximum current was 1.37 mA. It is indicated that the mortar-based cells attempt to supply electrical energy to a resistor, even though no water stimulates the formation of ionic bonds between a copper plate and a zinc plate. In other words, there were some intervals in the test when no every was supplied to the load; nevertheless, the mortar-based cells could restore energy and supplied to the load throughout the test period.In the test case with water added to the mortar-based cells, 3 pieces of mortar samples were also connected in series and supplied electricity to a 10-Ω resistor for 3 minutes.It is found that the maximum output voltage was 0.31 V and the maximum current was 1.92 mA. In this case, water can stimulate the formation of ionic bonds between a copper plate and a zinc plate. Despite stimulation from water, the result was opposite to that of the other case, i.e. the mortar-based cells hadrelatively constant supply voltage and the supply current changed over time.

Given the power supplied to the load, the mortar-based cell without water or dry cell could supply the average power of 21.192 mW, and the mortar-based cell with water or wet cell could deliver the average power of 15.858 mW. It is noted that the dry cell could supply 5.334 mW of power more than the wet cell because the dry cell has less internal resistance.

The results from this research are a guideline to a study of the behaviour of a solid-electrolyte electrical cellusing mortar. It can be further studied to invent an alternative and novel electricity source in the future.

Future work: Future work will develop mortar-based electrical cells as storage batteries to power future electric vehicles.

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