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Characteristics of BSCF–SDCC–Ag Composite Cathode Powder for Low-Temperature Solid Oxide Fuel Cell

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Abstract. A fuel cell is a type of clean energy that may be utilised in various applications across numerous sectors. Solid oxide fuel cell (SOFC) has attracted considerable interest as a fuel cell type due to its excellent efficiency and durability. However, SOFC may encounter specific challenges because of its operating temperature, which is generally high. This circumstance might negatively affect the overall system performance. New materials that can work with SOFCs in the low-temperature range (LT-SOFC) must be introduced to overcome the challenges. The milled barium strontium cobalt ferrite–samarium-doped ceria carbonate (BSCF-SDCC) composite cathode was introduced as a potential candidate for LT-SOFC material. Argentum (Ag) was added to the BSCF–SDCC composite cathode to act as a catalyst material for efficient performance. The characterisation of a BSCF–SDCC–Ag composite cathode was investigated under two properties, namely, chemical and physical. The X-ray diffraction results for phase identification showed that Ag addition exhibited compatibility with BSCF–SDCC composite cathode with no occurrence of impurities. The morphology and element observation showed that the composite cathode powder was well mixed, and all significant elements were uniformly and homogeneously distributed. The average percentage of porosity value was also obtained in the acceptable range (20%–40%). Specifically, it ranged from 21.12% to 22.50%. Therefore, the findings of this study prove that the addition of Ag can improve the performance of the BSCF–SDCC composite cathode, which is in line with the function of Ag as a catalyst material.

INTRODUCTION

The demand for global energy consumption grew by 5.8% in 2021, which is 1.3% more than the levels in 2019 [1]. The recorded data showed that the usage of fossil fuels as the primary energy consumption has exhibited slight decrement from 84.0% (2018) to 83.4% (2019) and 82.2% to 82.3% from year 2020 to 2021. The use of fossil fuels such as coal, oil and gas has played an important part in the world's various energy systems in driving the subsequent

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advances in technology, society and economic growth [2]. This rapid economic rise contributed to 5.7% of greenhouse gas emissions in 2021, which is nearly equivalent to the levels in 2019 [1].

The effect of greenhouse gas emissions gave a severe environmental risk to the atmosphere and local pollution linked to health issues. An alternative energy source should be developed rather than relying on fossil fuels as primary sources of energy generation to minimise the problem from continuously occurring. The hydrogen fuel cell is an alternative energy source with many advantages and benefits as a power source [3]. One of the types that currently dominate the market is solid oxide fuel cell (SOFC) [4].

SOFC has gained considerable attention because of its high efficiency and durability, and it is also considered very versatile with fuels compared with other kinds of fuel cells [5]. However, some obstacles are faced regarding the high operating temperature of SOFC during operation, which typically runs between 650 °C and 950 °C [6]. Studies have shown that the system efficiency also works well when the operating temperature is high, but an increase in fuel utilisation might reduce system performance [7]. This situation also increases processing cycle duration and manufacturing costs [8].

One way to tackle this problem is to lower the operating temperature (400 °C–600 °C) and identify the suitable material that can cooperate with this new development. According to the latest research, barium strontium cobalt ferrite (BSCF) is a perovskite-structure material that is a suitable cathode component because of its superb properties such as high ionic conductivity, superconductivity, magnetic resistance, ferroelectricity, outstanding catalytic activity for reduction and mobility of oxygen [9,10,11,12]. A noticeable advancement of the electrochemical properties in a series of the new cathode has been made due to impregnating a mixed conducting phase BSCF with samarium-doped ceria carbonate (SDCC). In addition, a catalyst material is added to the cathode composite to amplify the performance of the SOFC system given that this material can accelerate the reaction between anode and cathode. Based on previous research, argentum (Ag) acts as a catalyst material that helps increase the general oxygen surface exchange kinetics of BSCF cathode [13].

In this study, the BSCF–SDCC–Ag composite cathode was introduced and investigated to determine the characteristic (chemical and physical properties) of the cathode material for low-temperature SOFC (LT-SOFC). This research finding can be a benchmark for identifying new promising cathode material for LT-SOFC.

MATERIAL AND METHODS

The fabrication of the composite cathode powder involved commercial powder of BSCF ($Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}$), SDCC ($Sm_{0.2}Ce_{0.8}O_{1.9}$) (Kceracell, Korea), lithium carbonate (Li_2CO_3) and sodium carbonate (Na_2CO_3) (Sigma–Aldrich, USA) for creating BSCF–SDCC composite powder. The BSCF–SDCC was mixed at a ratio of 50:50. The SDCC was prepared by a combination of SDC with Li/Na carbonate at a ratio of 80:20 by using the wet milling method. The composite cathode powder was added with a few different weight percentages (1wt%, 3wt% and 5wt%) of Ag as catalyst material for creating BSCF–SDCC–Ag composite cathodes by using the dry milling method. The BSCF–SDCC–Ag composite powder underwent a calcination process at 600 °C. The mixed powder was then pressed to create a pellet sample. The sample then underwent a sintering process at 600 °C.

CHARACTERISATION METHODS

BSCF–SDCC–Ag powder and pellets were characterised for chemical and physical properties. The phase identification using X-ray diffraction (XRD) (Bruker D8 Advance, Germany) was performed using Cu Kα (λ = 0.15418 Å) at room temperature. Diffraction patterns were scanned using a step size of 0.02° over 2θ range from 20° to 90°. Scanning electron microscopy (SEM) (Hitachi Tabletop 3030, Japan) was conducted to determine the morphology of composite cathode powder, whilst element distribution was observed by energy dispersive spectrometry (EDS) (EDX Oxford Instruments). The Archimedes principle was used to examine the porosity and density of the composite cathode pellet sample.

RESULT AND DISCUSSION

Figure 1 shows the XRD pattern for the BSCF–SDCC and BSCF–SDCC–Ag (1wt%, 3wt%, 5wt%) composite powder after the calcination process at 600 °C. Figure 2 shows the XRD diffractogram of BSCF–SDCC and BSCF–SDCC–Ag (1wt%, 3wt%, 5wt%) pellet sample after being sintered at 600 °C. This testing and analysis were conducted to identify the chemical phases of the composite cathode powders and pellet after going through calcination and sintering process. Comparing the two figures shows that the XRD patterns of the powder and pellet samples are nearly identical. The BSCF spectrum is generated at JCPDS No: 00-055-0563, which is the same reported pattern as the commercial BSCF powder. The BSCF also has a cubic lattice structure and space group Pm-3m. According to previous research, cathodes with cubic crystal structures utilised in SOFCs have strong ion mobility and high ionic conductivity, which improves system performance [15]. The commercial powder SDC, Li_2CO_3 and Na_2CO_3 also demonstrate great purity with no secondary peak occurring because their spectrum is observed at the JCPDS No: 01-75-0157, 00-022-1141 and 01-070-9248, respectively. The Ag commercial powder was analysed, and it is discovered at the JCPDS No: 00-004-0783 with a face-cantered cubic lattice structure. The Ag peak can only be observed at 38° in both figures and shows an increase in intensity alongside the rise in overall Ag composition.

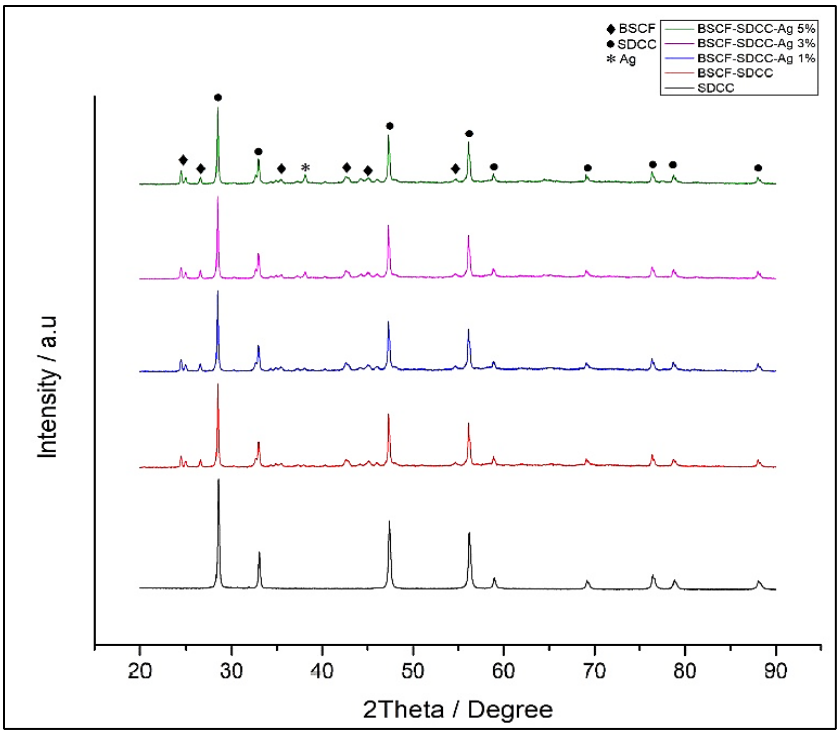


FIGURE 1. XRD pattern of BSCF–SDCC–Ag composite cathode powder calcined at 600 °C

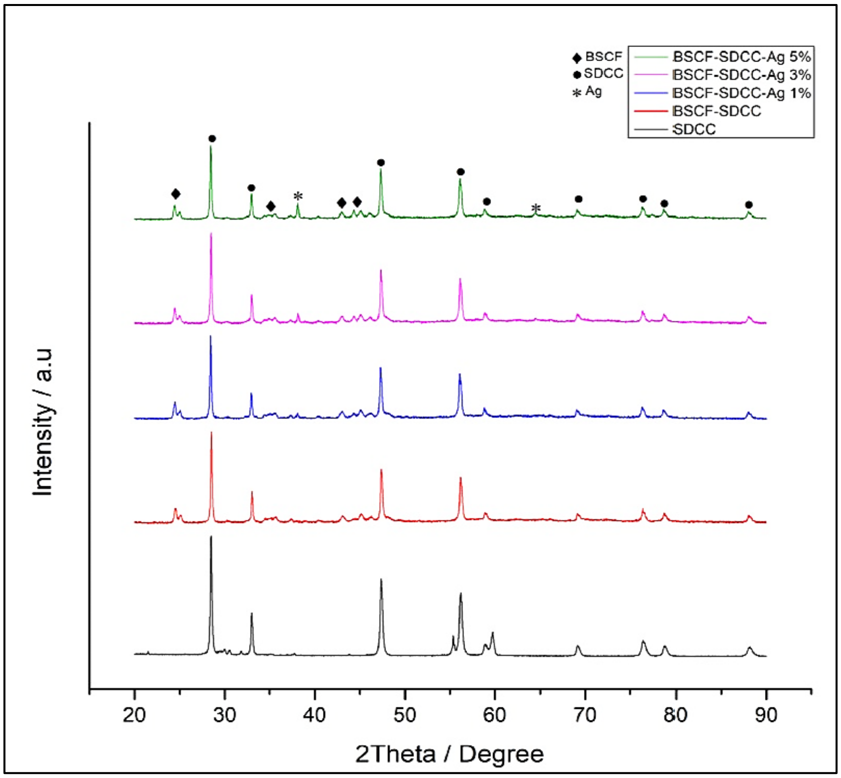


FIGURE 2. XRD pattern of BSCF–SDCC–Ag pellet sample sintered at 600 °C

Figure 3 displays the surface morphology of the BSCF–SDCC and BSCF–SDCC–Ag (1wt%, 3wt% and 5wt%) cathode composite powder. The sample was calcined at 600 °C. The observation shows that the particle shape of the composite cathode powder tends to agglomerate as the percentage of Ag increases due to finer particles which lead to the increment in densification and reduction in the porosity of samples. However, this scenario must be avoided at all costs because it can potentially hinder the flow of oxygen into the cathode side [16].

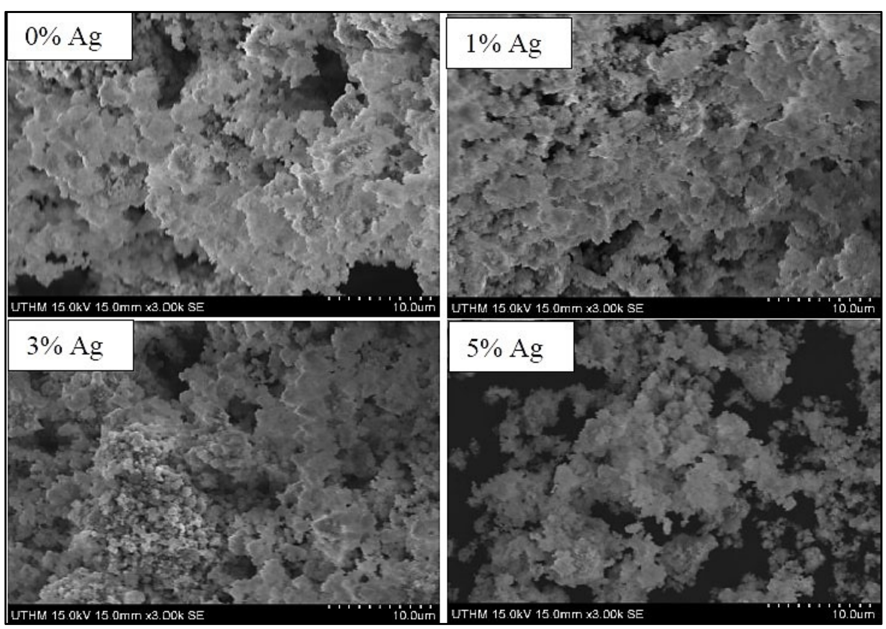
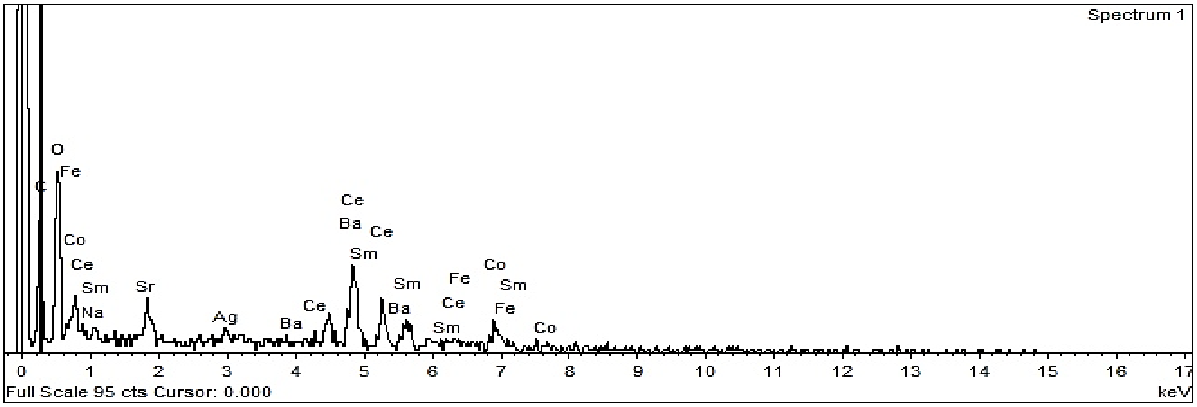
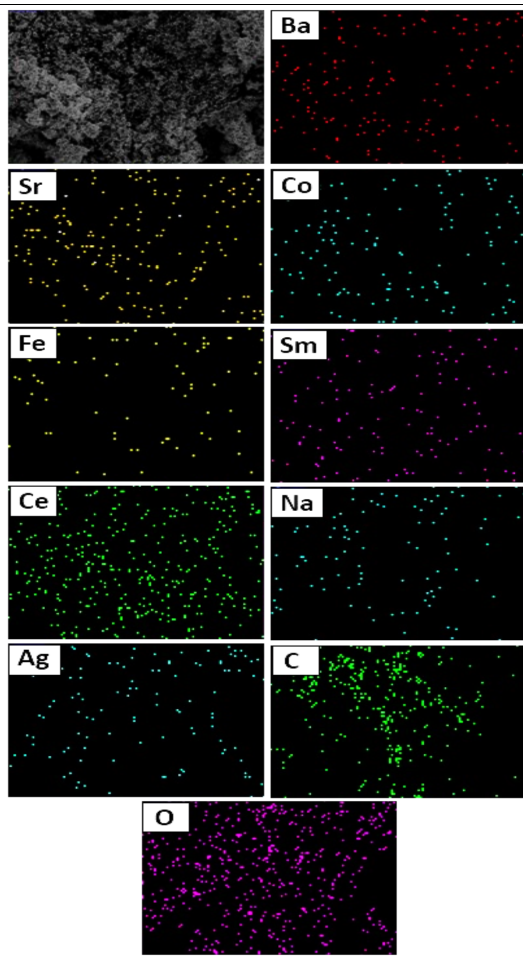


FIGURE 3. SEM image of BSCF–SDCC–Ag with 0 wt%, 1 wt%, 3 wt% and 5 wt% Ag

Figure 4 shows the EDS mapping of the BSCF–SDCC–Ag 5 wt% composite powder. The results show that most of the significant elements are observed on the mapping, such as barium (Ba), strontium (Sr), cobalt (Co), ferrite (Fe), samarium (Sm), ceria (Ce) and sodium (Na). However, lithium (Li) is not detected due to its low atomic mass [17]. The sample is homogenously distributed throughout the milling process and mixed uniformly. The graph of EDS intensities and the quantitative value of the element are shown in Figure 4. The mapping graphic is coloured in various hues to show that each element is spread uniformly over the scanning area.





Element	Atomic (%)
Barium (Ba)	1.21
Strontium (Sr)	0.65
Cobalt (Co)	2.64
Ferrite (Fe)	0.21
Samarium (Sm)	1.28
Ceria (Ce)	3.50
Sodium (Na)	0.19
Argentum (Ag)	0.28
Carbon (C)	60.95
Oxygen (O)	29.08

FIGURE 4. Element distribution and EDS spectrum of BSCF–SDCC–Ag 5 wt% composite cathode powder calcined at 600 °C

Table 1 shows the porosity and density of BSCF–SDCC and BSCF–SDCC–Ag pellets. The recorded data demonstrate a decrease in porosity value for the sample without and with Ag. This situation shows a good side effect of Ag addition that helps in reducing the porosity state of the sample. The density value also shows an increment by increasing Ag addition. However, the samples of 3 wt% and 5 wt% have a higher density value than the sample of 1 wt%. This occurrence may be due to that the sample is much denser and expected to have lesser porosity. However, the difference in density between the samples of 1 wt%, 3 wt% and 5 wt% is minimal, and the porosity percentage does not differ by more than 1%. As reported by previous research, a good porosity value for SOFC is in the range of 20%–40% [13,14]. Thus, the porosity values of all the samples are in the acceptable range.

TABLE 1. Porosity and density average values of BSCF–SDCC–Ag pellet

Ag Composition	Porosity (%)	Density (g/cm^3)
0	22.50 ± 1.88	3.63 ± 0.06
1	21.12 ± 0.65	3.74 ± 0.03
3	21.69 ± 0.41	3.76 ± 0.01
5	21.78 ± 0.60	3.77 ± 0.01

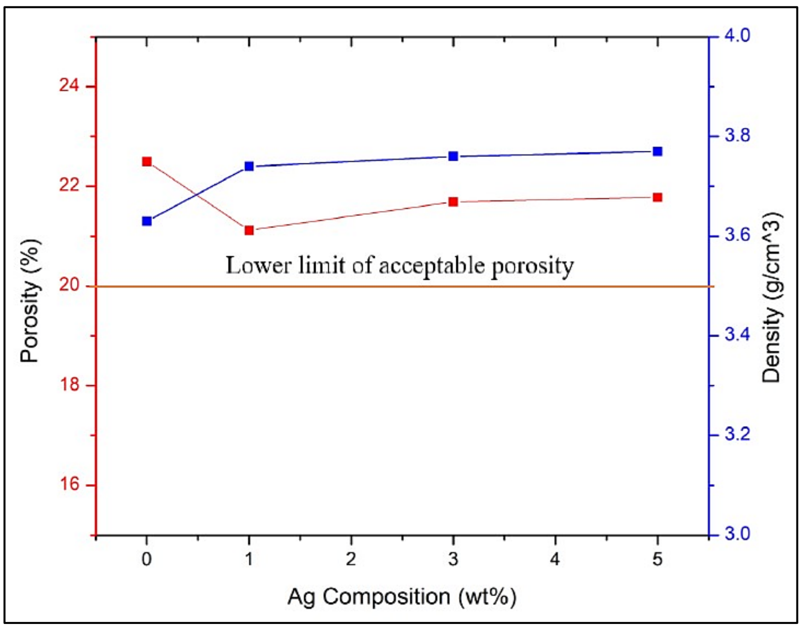


FIGURE 5. Porosity and density of BSCF–SDCC and BSCF–SDCC–Ag (1 wt%, 3 wt% and 5 wt%)

CONCLUSION

BSCF–SDCC and BSCF–SDCC–Ag (1 wt%, 3 wt% and 5 wt%) composite cathode powders are fabricated successfully. The characterisation of chemical and physical properties shows good material compatibility with each other. The XRD pattern of the BSCF–SDCC and BSCF–SDCC–Ag shows that all samples are discovered at their peak with no secondary phase occurring. The peak intensity also increases as the Ag composition rises. The morphology image also shows that the composite cathode powder has a tendency for the particles to agglomerate as the percentage of Ag increases. The EDS mapping for BSCF–SDCC and BSCF–SDCC–Ag shows that all elements are well distributed. Moreover, the porosity of all samples is in the range of 20%–40%, which is acceptable for SOFC cathode. BSCF–SDCC–Ag has a porosity value from 21.12% to 22.50%. Notably, adding Ag to BSCF–SDCC composite cathode improves its properties, which is consistent with the aim of adding Ag as a catalyst material.

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REFERENCES

1. R. Bousso. Global energy consumption topped pre-pandemic levels in 2021, says BP. (2022).
2. H. Ritchie, M. Roser and P. Rosado. Energy, Published online at OurWorldInData.org. (2020).
3. P. E. V. de Miranda. Hydrogen Energy: Sustainable and Perennial. Academic Press, 1-38 (2019).
4. A. Coralli, B. J. M. Sarruf, P. E. V. de Miranda, L. Osmieri, S. Specchia and N. Q. Minh. Fuel Cells. Academic Press, 39-122 (2019).
5. K. Al-Khori, Y. Bicer and M. Koc. Integration of Solid Oxide Fuel Cells into Oil and Gas Operations: Needs, Opportunities and Challenges. Journal of Cleaner Production, 245, 118924 (2020).
6. H. Ren, Y. H. Lee, E. A. Wu, H. Chung, Y. S. Meng, E. E. Fullerton and N. Q. Minh. Nano-Ceramic Cathodes via Co-Sputtering of Gd-Ce Alloy and Lanthanum Strontium Cobaltite for Low-Temperature Thin-Film Solid Oxide Fuel Cells. Applied Energy Materials, 3, 9, 8135-8142 (2020).
7. S. Huang, C. Yang, H. Chen, N. Zhou and D. Tucker. Coupling Impacts of SOFC Operating Temperature and fuel Utilization on System Net Efficiency in Natural Gas Hybrid SOFC/ GT System. Case Studies in Thermal Engineering, 31, 101868 (2022).
8. M. Irshad, K. Siraj, R. Raza, A. Ali, P. Tiwari, B. Zhu, A. Rafique, A. Ali, M. K. Ullah and A. Usman. A Brief Description of High-Temperature Solid Oxide Fuel Cell's Operation, Materials, Design, Fabrication Technologies and Performance. Applied Sciences, 6, 75 (2016).
9. U. A. Yusop and H. A. Rahman. Properties of BSCF-SDC Composite Cathode Powder for Low-Temperature Solid Oxide Fuel Cell. Journal of Physics: Conference Series, 1082 012029 (2018).
10. S. Hussain and L. Yangping. Review of Solid Oxide Fuel Cell Materials: Cathode, Anode and Electrolyte. Energy Transitions, 4, 113-126 (2020).
11. M. Mosialek, M. Zimowska, D. Kharytonau, A. Komenda, M. Gorski and M. Krzan. Improvement of $La_{0.8}Sr_{0.2}MnO_{3-\delta}$ Cathode Material for Solid Oxide Fuel Cells by Addition of $YFe_{0.5}Co_{0.5}O_3$. (2021).
12. U. A. Yusop, N. F. A. Rahman, Y. N. A. Lowrance, Z. Jaidi, M. F. Tukimon, M. A. Azmi, A. Ismail, S. Mahzan and H. A. Rahman. Effect of Nb and Zn Element Doping on Barium Strontium Cobalt Ferrite-based Cathode for Solid Oxide Fuel Cell – A Short Review. Malaysian Journal of Microscopy, 18, 1, 226-244 (2022).
13. U. A. Yusop, H. A. Rahman and K. H. Tan. Effect of Ag Addition on The Structural Properties of $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$-$Sm_{0.2}Ce_{0.8}O_{1.9}$. The International Journal of Integrated Engineering, 11, 7, 169-175 (2019).
14. Bakar, M. S. A., Rahman, H. A., Mohammad, S. F., Ahmad, S., & Muchtar, A. (2017). Morphological and Physical Behaviour of LSCF-SDCC-Ag Composite Cathode with the Incorporation of Ag as an Additive Element. Journal of Physics: Conference Series, 914, 012011 (2017).
15. H. A. Rahman, L. Agun, N. K. Hoa, S. Ahmad and N. A. Nordin. Effect of Binary (Lithium/Natrium)2 Carbonates on The Phase and Microstructural Stability of LSCF-SDC for Low-Temperature Solid Oxide Fuel Cells. Sains Malaysiana 49, 12 (2020).
16. Bakar, M. S. A. Kesan halaju pengisaran dan suhu pengkalsinan terhadap komposit katod LSCF-SDC karbonat. Universiti Tun Hussein Onn Malaysia: Degree's Final Year Project Thesis, 2017.
17. K. H. Ng, S. Lidiyawati, M. R. Somalu, A. Muchtar and H. A. Rahman. Influence of Calcination on The Properties of Nickel Oxide-Samarium doped Ceria Carbonate (NiO-SDCC) Composite Anodes. Procedia Chemistry, 19, 267-274 (2016).