Effect of Zinc Oxide as an Additive on the Mechanical and Physical Properties of Singgora Roof Tile

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Abstract

The Singgora roof tile has been used widely as roofing material in traditional Malay housing in olden days. However, few factors such as high moisture –absorption, fungus growth and easily crack to make it less competitive and enduring falling of purchaser demand nowadays. These drawbacks are due to the mechanical and physical properties of the roof itself. Substantial work should be carried out to overwhelm the mentioned shortcomings of Singgora roof tile in sustaining the traditional legacy. Therefore, the inclusion of additive like Zinc Oxide (ZnO) in the production of Singgora roof tile can improve its mechanical and physical properties. Six different compositions of ZnO (0, 5, 10, 15, 20, and 30 wt. %) mixed with clay powder were fired in a furnace for 16 hours at a temperature of 800 °C. The final product of ZnO incorporation with clay roof tile was characterised for mechanical and physical properties such as SEM observation, density and porosity measurements, and three-point bending test investigation. From the result, 10 wt. % ZnO addition shows the optimum result which consists of low porosity, high density and also high flexural strength.

Keywords: Singgora, clay, roof tile, ZnO, SEM

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Introduction

Singgora tile is a handmade traditional roof covering for buildings which broadly spotted preponderantly in Kelantan and Terengganu [1] before the emergence of modern roofs. Its application included roof covers for mosques, pavilions, museums, chalets, gazebos as well as palaces. The Singgora's name itself is originated from Thai words means Lion City which contemplated after lion shape of a hill in Songkhla, Thailand [2]. The manufacturing history of Singgora tiles in Malaysia is believed by many scholars was begun from Southern Thailand [3]. Due to the migration process, trading and demand by the Thai communities around early 18^{th} it became part of the Malay traditional architecture [4]. Singgora tiles are the most unique, aesthetic and remarkable vintage roofing materials, especially in their shape and colour features. The appearance of the Singgora looks like fish scales, once arranged in the roof pattern. On the other hand, the pale orange colour which expresses the natural complexion to the building.

Singgora tiles are manufactured using moulded clay and then burnt in a kiln. This plain clay tile also has the thermal mass characteristic to help the building react to temperature variations throughout the day. During peak temperature, Singgora tiles will absorb the heat, rather than transfer it to the living space [4]. This keeps the interior of the home comfortable during peak temperature hours. On the other hand, the absorbed heat is then released at night to keep the home warm. Nevertheless, Singgora tiles help to improve building comfort and reduce the demands for peak energy. Besides, the Singgora tiles are installed to allow greater airflow between the tile and the roof batten [5]. Thus, the insulating properties of the roof are improved. However, these tiles are now obsoleted with the elapsing of time due to high moisture absorption, and easy experience brittleness and crack formation.

Addition of metal oxide into the mixture of clay during sample preparation can increase the durability towards ceramic material such as Singgora roof tile. The use of metal oxide in ceramic preparation is promised to allure attention in high strength, high surface hardness, excellent ductility, and toughness [6]. Among the metal oxides, zinc oxide (ZnO) has been intensively researched because of its unique chemical and physical properties, considered as a multifunctional material which make it adequate in different applications in industry, research, and health [7]. ZnO is widely applied in various applications, from ceramics to pharmaceuticals and in fact drug delivery, bioimaging, and antimicrobial therapy [8]. Therefore, the aim of this study is to investigate the mechanical and physical properties of clay mixed with Zinc oxide (ZnO) in order to produce the new brand of Singgora/ ZnO roof tile.

Materials and Methods

Samples Collection and Preparation

The raw clay that was obtained from paddy fields were dried and crushed into small pieces. Then, it was dried using an oven at 100 °C for 2 hours before it was ground into a fine powder using Rocklabs Bench Top Mill Crusher. The fine clay powders were mixed with ZnO powders. Six different compositions of ZnO were used which are 0, 5, 10, 15, 20 and 30 wt. % where 0 wt. % was used as a control in this research. The sample was moulded by using the mould made from Plaster Of Paris (P.O.P). Once the shaping process finished, the sample was dried under the sun for two days before the firing process takes place. The firing process of the sample was performed in a furnace at a temperature of 800°C for 16 hours [2].

Scanning Electron Microscopy (SEM)

The samples of Singgora roof tiles added with ZnO were observed using a JOEL JSM-IT 100 Scanning Electron Microscope (SEM) under x500 magnification. The ceramic samples were cut cross-sections into small pieces and were placed on top of carbon tape on SEM sample mount to allow electron conductivity for better image scanning. SEM morphology analysis was conducted to scrutinise the dispersion of zinc oxide with clay. Information regarding the pore formation and crack propagation of the samples were collected.

Three-point Bending Test

Three-point bending is one of the standard test methods for mechanical testing to determine the flexural strength of the sample by three-point loading. Universal Testing Machine (model Instron 3366) with a load capacity of 50 kN was used according to ASTM D790 to study the flexural strength of the produced clay roof tiles with different ZnO composition. In this test, Singgora roof tile with a rectangular or flat cross-section sample is placed on two parallel supporting pins. The loading force is applied in the middle by means loading pin. The load was brought to stop once the sample tested break into two.

Water Absorption Test

Water absorption test was performed to study the density and porosity of the clay roof tile after the firing process. Study of density and porosity of material helps to determine the fluid transport of a material [9]. Density can be defined as mass per volume of a substance typically with units of g/cm3 or kg/m3. Meanwhile, porosity is a volume ratio and dimensionless or usually known as a fraction or per cent. Water absorption test (the density and porosity) of the clay roof tile was determined according to ASTM D570 [10] using a density kit.

Results and Discussion

Morphological Analysis

Figure 1 shows the SEM observation at 500x magnification of raw clay sample obtained from commercial Singgora roof tile. The SEM analyses on the surface of the commercial roof tile were conducted to recognise any existing withdraws for further improvement. Morphological analysis on the commercial roof tile sample without ZnO addition shows that the surface structure of the sample has pore, hairline crack and tiny pit formations. As can be seen in the figure, the pore formation represents with striped arrow meanwhile hairline crack and tiny pit formation is marked with a dotted arrow. The defects on the surface structure of the sample influenced the performance and durability of clay tile. This structural defects on the commercial product might be occurred due to the equipment fault during production [11].

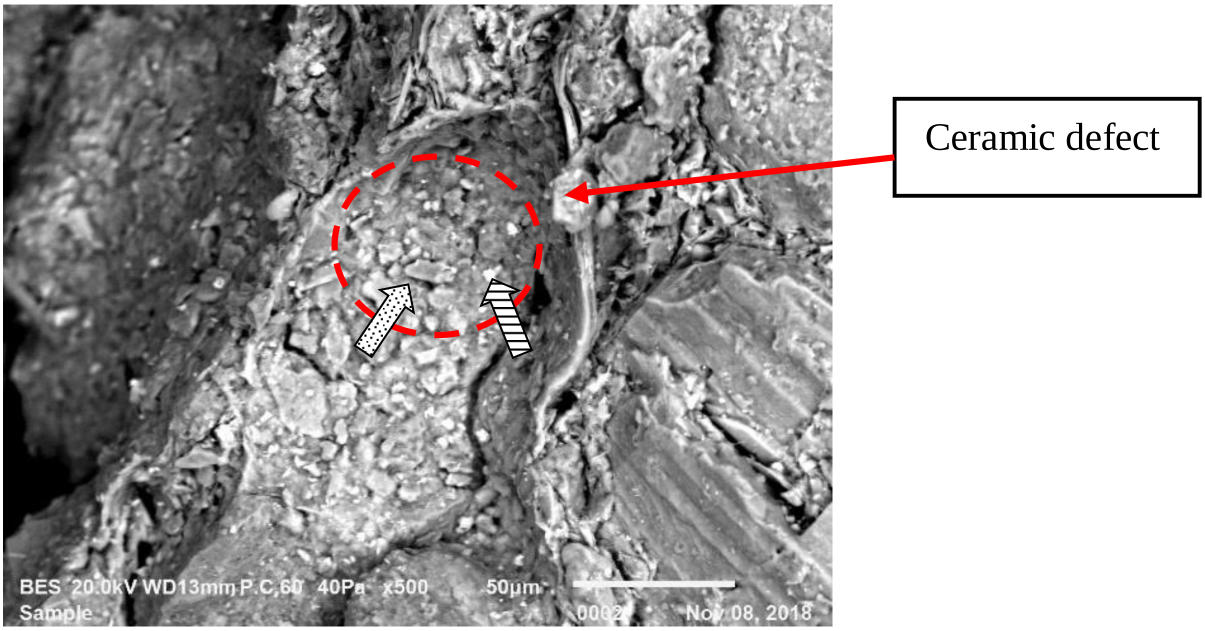

Figure 1: SEM morphology of ceramic defect on commercial Singgora roof tile (without ZnO addition)

Meanwhile, the SEM morphological images obtained from the surface of clay roof tiles with different addition of ZnO (5, 10, 15, 20, and 30 wt. %) were presented in Figure 2. Two arrows of dotted and striped backgrounds pointed into the images represent the crack and pore formation on ZnO/ clay roof tile respectively. Based on the obtained images, there was no agglomeration of ZnO powder formed in the structure of the samples. These showed that the clay mixed well with the ZnO. Besides, according to Valant and Suvorov [12], microstructural change of the sample can be observed from the pore characteristics through the formation of pore size. Usually, the pore size distribution closely related to the presence of cracks and voids. As can be seen in the morphological analyses of the clay roof tile samples with different addition of ZnO, the pore size lessens with the increase of ZnO composition. On the other hand, there were also crack formation on the clay roof tile samples which related to the pore size distribution. It is observed that the crack formation on the sample decrease as the ZnO composition increase. As a matter of fact, clay roof tile that was added with ZnO shows a reduction in pore size and crack formation compared to the commercial clay roof tile without ZnO addition.

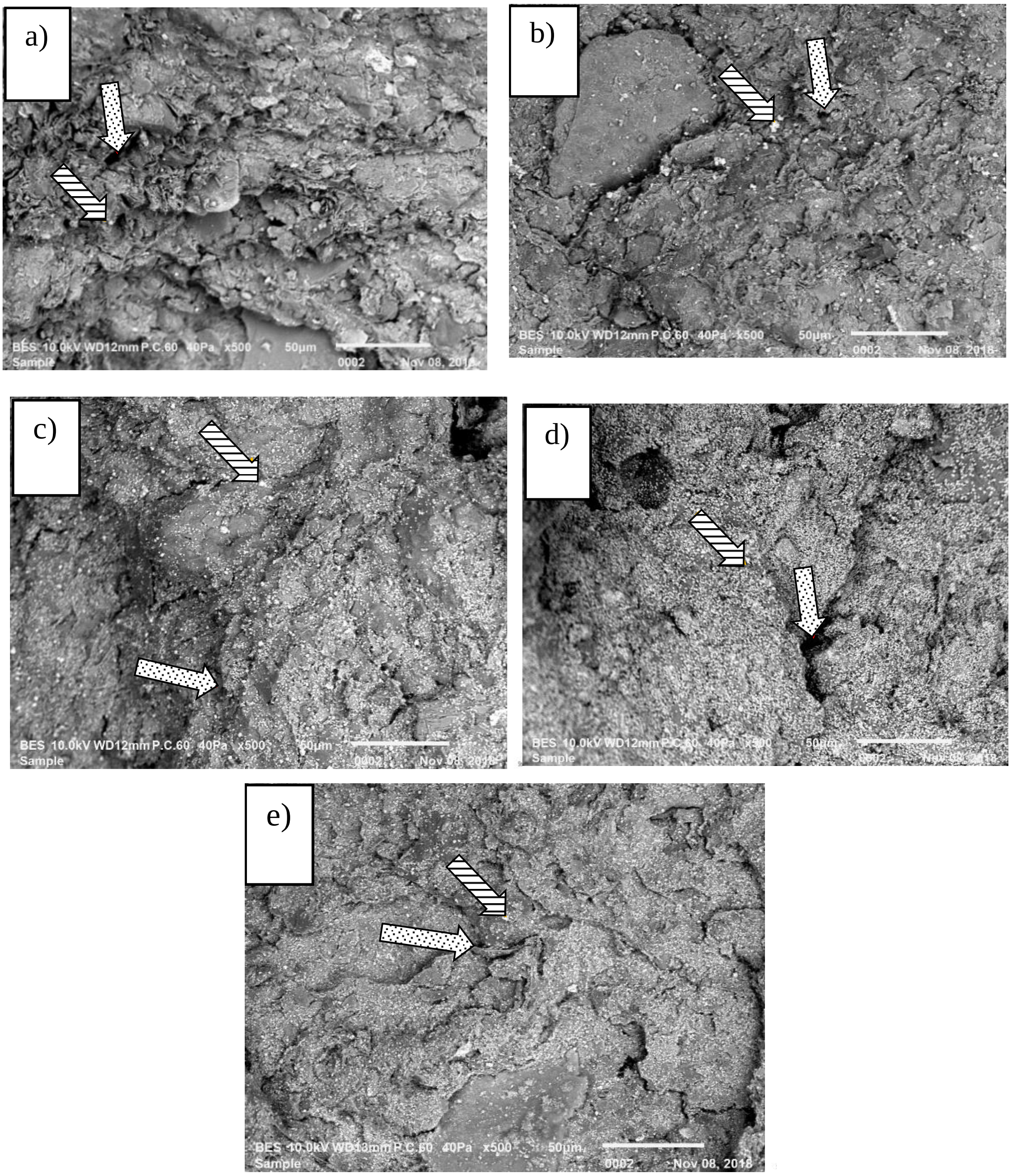

Figure 2: The crack and pore formation of SEM morphology on clay roof tile with ZnO composition of; a) 5 wt. %, b) 10 wt. %, c) 15 wt. %, d) 20 wt. % and e) 30wt. %

Density and Porosity

Figure 3 presents the results of the water absorption test for the density and porosity of the clay roof tile with different ZnO compositions. It can be seen that the highest density is obtained by clay tile added with 30 wt. % of ZnO with 2.255 g/cm3, followed by 20 wt. % (2.201g/cm3), 15 wt. % (2.136 g/cm3), 10 wt. % (2.092 g/cm3), 5 wt. % (2.001g/cm3) and 0 wt. % (1.972 g/cm3). It is well known that the increase in density contributes to the increase in mechanical strength. Therefore, it can be claimed that the clay tile of 30 wt. % ZnO with the highest density attains relatively the highest mechanical strength compared to other sample compositions. The particle size of the sample become denser due to the grain shifting as pressure increases [13]. In contrast to the density, it is found that the highest porosity is possessed by clay roof with ZnO addition of 0 wt. % (37.685%) followed by 5 wt. % (33.945%), 10 wt. % (32.354%), 15 wt. % (32.115%), 20 wt. % (31.567%) and 30 wt. % (24.047%). Hence, it can be seen that the porosity of sample increases with the decreases in the density. The porosity of sample increases due to the high water absorption rate because of the easy water penetration into the sample [14]. According to Wu et al. [15], high porosity resulted in low thermal conductivity and good insulation.

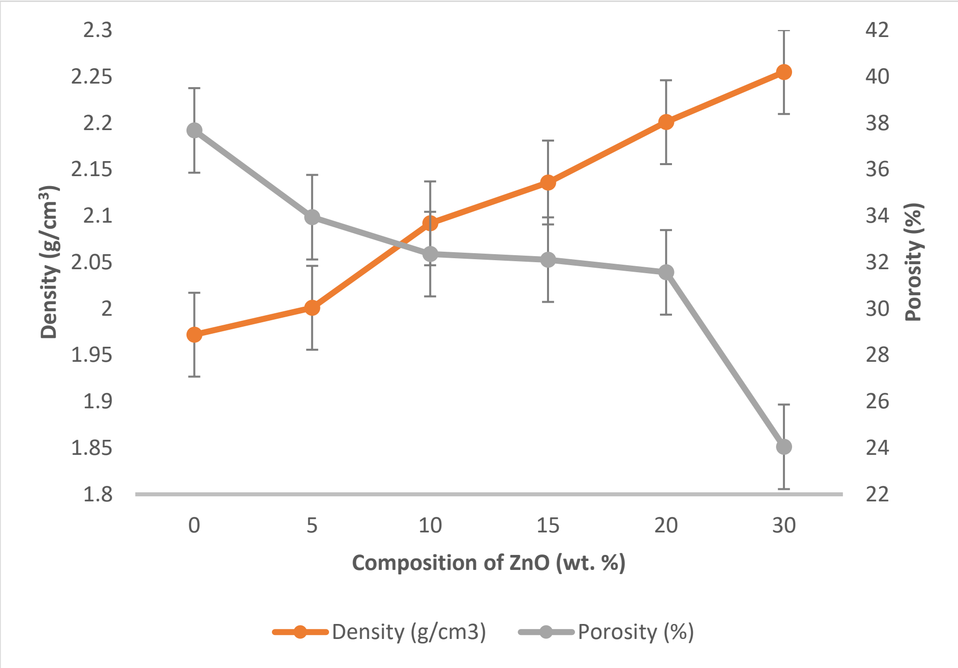

Figure 3: Porosity and density of clay roof tile with different ZnO composition

Flexural Strength

Figure 4 presents the flexural strength of four clay roof tile samples with different composition of ZnO. According to this figure, it can be identified that the order from the highest to the lowest of the flexural strength of clay roof tile regarding the ZnO composition is 10 wt. % (5.619 MPa), 5 wt. % (4.572 MPa), 0 wt. % (4.064 MPa), 20 wt. % (2.697 MPa), and 15 wt. % (2.327 MPa). From the collected data, the strength of the clay roof tile sample reaches its optimum peak at ZnO addition of 10 wt. % and start to decline right after that. It is suggested that the flexural strength was substantially influenced by the densification/porosity of metal oxide-ceramics. Unfortunately, there is no available data obtained for clay roof tile at 30 wt. % of ZnO composition due to the thermal shock experiences twice by the sample during the firing process in the furnace. This is related to the fact that the flexural strength of ceramic material influenced by the firing of the sample during the firing process [5]. Therefore, if the sample experienced thermal shock during the firing process, it is likely that the flexural strength data distribution is not accurate. This thermal shock phenomenon occurred due to the incapability of clay roof tile sample to allow soaking temperature during the firing process.

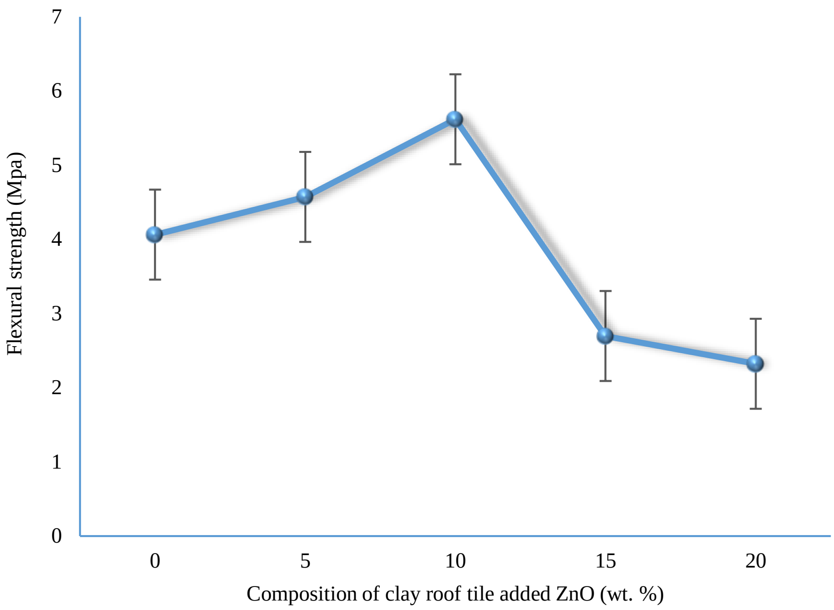

Figure 4: Flexural strength for clay roof tile with different ZnO composition

Conclusion

The incorporation of ZnO into the ceramic has improved the properties of Singgora roof tile. Based on the findings, 10 wt. % ZnO shows remarkable improvements. Lower composition ZnO portrays low pore size and crack formation on the surface structure. It exhibits quite high density and low porosity values. The mechanical characterisation for three-point bending also shows that the strongest flexural strength at 5.619Mpa is gained by Singgora roof tile with the addition of 10 wt. % ZnO. Thus, the addition of ZnO into clay roof tile improved the physical and mechanical characterisation of clay roof tile sample. However, there are two factors need to be considered for the future of the Singgora/ ZnO roof tile study which is the shrinkage rate of the Singgora roof tile, and the proper firing technique to avoid thermal shock occurrence. These additional experimental investigations and test data are required for the improvement of the Singgora/ ZnO roof tile performance.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards

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