Why Does My Concrete Tile Fragile? A Case Study: Genteng Beton Indonesia Ltd

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Abstract. A concrete roof tile is one of building materials which has been produced and used for roofing since 1976. In 2016 there was a big case happened on this material due to losing durability and becoming brittle after 8 months of instalation. The study was carried out to evaluate the properties of roof tiles which were installed on a roof in 2016 and produced after 2016. These properties were tested by EDX and SEM to obtain the concentration of each element and to determine the dynamic viscosity of each element. This study found that brittle concrete tile contained of Sr, Cl, S and Mn. However some of samples had no S and Mn. Element of Sr appeared on all fragile protected concrete roof tiles. It is supposed that the presence of Sr caused microcracks due to its strong reaction in humid condition. Therefore it needs to revise the regulation dangerous elements in roof tiles as mentioned SNI 0096-2007 which accord to the condition of humidity in Indonesia.

Keywords: Concrete, Fragile, Roof Tile, Moisture

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1. Introduction

Concrete tiles are one of the choices for roof covering nowadays because their service life can reach up to 20 years, can sustain winds in excess of 125 mph that would strip off most other roofing materials. Concrete roof tiles are designed to last the lifetime of a house. Concrete tile are cement-based building materials with a thickness of ±1.5 cm. Roof tiles are important for roofing in housing construction. Housing construction elements degrade due to moisture, such as stucco, concrete, concrete roof tile, masonry, and flooring. Several researchers have paid attention to concrete rooftiles and cement-based mixtures.

Concerning the roof, there are many different elements that will affect the final product. Seepage testing on flat concrete tiles using a mixture of sand and Lumajang shows better performance compared to ordinary sand [1]. Total replacement of sand with basalt powder in concrete roof tile is very possible [2]. Different roof tiles are made of tired ceramics and concrete, polymer, composite and metals. In this study, digital logic method (DLM) was employed in analyzing properties obtained for sample tested. DLM involved ranking of samples based on values obtained for figure of merit (FOM). Granite dust of 2% and 98% polypropylene moulded by compression shown highest durability and sustainability [3]. The compressive strength of the tiles produced with 30 percent PET waste composition was greater than that of cement concrete (at 28 days of curing) for residential buildings. As a result of this low water absorption and eco-friendliness, PET waste can be used for roof tiles at 30 percent PET substitution based on the test results [4]. The manufacture of concrete roof tiles with added materials of coconut fibre and styrofoam has been investigated [5]. Expansion investigations were carried out on cement tiles and aggregates with marble waste sludge [6]. Concrete rooftiles have a fairly large own weight. Trials to overcome this problem and the problem of the need for large quantities of cement have been carried out using geopolymer concrete and artificial lightweight coarse aggregate [7]). The use of 5% replacement of rice husk ash and 25% replacement of copper slag for rooftiles obtained the best and most comfortable results from test of water absorption, compressive and flexural strength [8], while addition of 10% rice husk ash showed results which is better than OPC at 28 days [9]. Experimental study on the use of waste polyethylene terephthalate (PET) and river sand in roof tile production was published [10]. Food and coal industry waste and natural fibres are used in making concrete roof tiles [11]. There is not much difference in the modulus of elasticity between the percentage composition of corn cob ash and kenaf fibre in cement for rooftile, but the difference is clearly visible in the modulus of rupture and does not show a significant effect on the value of the modulus of elasticity [12]. Tests' results proved a slight decrease in concrete compressive strength as plastic fibre was added compared with the reference mix [13].

The results of comparative life cycle assessment of ceramic versus concrete roof tiles in the Brazilian context show that ceramic tiles appear to have less impact than concrete tiles on climate change, resource depletion and water withdrawal, while for the remaining damage categories, human health and ecosystem quality, the difference between the two alternatives was too low to be considered significant [14].

Roof tiles must be chosen according to the climate and to withstand natural forces that can affect the roof. The manufacture of concrete roof tiles with the concept of environmentally friendly materials using rice husk ash and polyethylene waste has been carried out [15]. Throughout its service life, it is critical to receive direct weather changes. Indonesia has a humid tropical climate, with an average humidity of ± 72% with the lowest humidity of 50% occurring on a few days in three months, and temperature between 26°C – 34°C throughout the year [16]. Regulation of concrete tile SNI 0096, 2007 [17] requires a maximum water absorption of 10%, no water should drip within 20 hours. In addition, other required tests include visible properties, size, flatness, and flexural load test with the condition of 10 specimens in a room with a temperature between 15°C-30°C and a minimum relative humidity of 40%. The humidity condition of 40% in the flexural load test is not following the nature of Indonesia. Extensive damage to tile roofs over the last few years was stated by Huang et al., 2009 [18]. Even for weaker storms, the tile was damage. This has raised concern about construction practices and codes [18]. The widespread damage to concrete tiles also occurred in Indonesia.

One of the precarious companies in Indonesia, in 2015 produced around 4,200,000 pieces which fulfilled 10,000 people's houses. This company has been producing concrete tiles since 1976 using cement from one factory until August 2020 and using the same material. Although the source of the material and the way of working did not change, there were complaints due to the damage as shown in Fig. 1. The damage occurred after the roof tile were installed for ± 8 months. The critical damage occurred in production starting March/ April 2018.

Fig. 1. Tile damage on a housing in Duta Pakis Residence, Indonesia.

Because of the damage, the developer is not willing to pay for the reason that the quality is not good [19]. The impact of tile damage occurred in 23 companies, 13 individuals, and more than 50 projects. Many moral and material losses were experienced by the Manufacturers because of this matter.

The cause of the destruction of the concrete has been investigated by the cement party concerned but did not find things that caused the destruction. The compressive strength test on the combination of materials used showed a decrease in compressive strength at the age of 90 days. Because concrete tiles are used in almost all housing, if the cause of the destruction is not known, it can have an impact on the national concrete tile industry. Moral and material losses must be borne by the Manufacturer.

2. Materials and Method

2.1. Materials

The material used in this study is roof tile from one factory which consists of roof tile produced in 2016 installed in a house, and roof tile produced after 2016 namely: (1) exposed stock 2019, (2) exposed flat, (3) protected stock 2019, (4) exposed project 2020, (5) exposed, (6) protected stock surface damage 2019. The materials for making concrete roof tiles are presented in Table 1. Water to cement rasio is 1.328.

Table 1 Materials for making concrete rooftiles.

Material	kg	Material	kg
Cement	40	Bottom ash	7.3
Cilegon sand	71.3	Water	53.12
Sudamanik stone ash.	13		

The cement tested was not cement used for the production of fragile roof tiles because it had run out, but cement from shops that became customers after the supply from the cement factory was stopped. The type of cement ordered is PPC.

2.2. Method

The roof tile produced in 2016 became a reference because the quality was still good until the time of testing and there were no complaints. Samples were tested with Energy Dispersive X-ray Fluorescence (EDX) from the Physics Laboratory of the Universitas Indonesia and Scanning Electron Microscopy (SEM) from the Integrated Laboratory of the University of Lampung. The number of samples for EDX testing to obtain the concentration of each element is 2 units, and to find the dynamic viscosity of each element and ion energy is 1 unit. The number of samples for SEM testing is 1 piece of each type of tile with a magnitude of 500 and 5.00 K. This is done so that the microstructure can be seen as a whole. From the concentration data of 2 samples of each element, calculations were made for C_3S, C_2S, C_3A, and C_4AF according to SNI 15-2049 [20), 2004 as follow:

$$C_3S = -(4.071\ CaO - 7.6\ SO_3 - 6.718\ Al_2O_3 - 1.43\ Fe_2O_3 - 2.852\ SiO_2) \quad (1)$$

$$C_2S = -\ (2.867\ SiO_2\ - 0.7544\ C_3S) \quad (2)$$

$$C_3A = 2.65\ Al_2O_3 - 1.692\ F_2O_3 \quad (3)$$

$$C_4AF = 3.043\ Fe_2O_3 \quad (4)$$

The calculation results of the two samples on each element are compared and analyzed. From the EDX data, it can be seen the presence of elements that are different from the elements contained in the 2016 production roof tile. From the literature study, the properties of the different elements were studied. Elemental relationship and dynamic viscosity, from damaged roof tiles and 2016 production tiles were compared. The results of the analysis were correlated with SEMs of both magnitudes.

The cement being tested is the newest cement, not the cement used for roof tiles which are fragile because they have run out.

3. Results and Discussion

3.1 Results

The results of the study are divided into several parts, as follows:

3.1.1 Calculation Results C_3S, C_2S, C_3A and C_4AF.

The results of the calculation of C_3S, C_2S, C_3A, and C_4AF from 2016 roof tiles, and damaged tiles are presented. From the 2 samples for each type of tile, different values of C_3S, C_2S, C_3A, and C_4AF were obtained but produced the same C_3S/C_2S, C_3A/C_2S, C_4AF/C_2S ratio (Table 2).

Table 2. C_3S, C_2S, C_3A and C_4AF of 2016 produced roof tiles and damaged tiles

Element	Concentration, %													
	Prod 2016-a	Prod 2016-b	Exposed stock 2019 Sample 1a	Exposed stock 2019 Sample 1b	Exposed Flat 1, 2018 Garuda Sample 2a	Exposed Flat 2, 2018 Garuda Sample 2b	Unprotected Project 1 2020 Sample 3a	Unprotected Project 2 2020 Sample 3b	Protected 1 2019 Sample 4a	Protected 2 2019 Sample 4b	Exposed 2021 Sample 5a	Exposed 2021 Sample 5b	Protected stock surface damage 2019 Sample 6a	Protected stock surface damage 2019 Sample 6b
Al	5.74	1.85	5.66	2.04	3.87	0.97	6.34	2.34	4.96	1.86	5.54	2.2	5.69	2.13
Si	21.02	6.78	20.96	7.55	14.23	3.55	21.12	7.81	19.8	7.44	18.46	7.31	20.45	7.64
S	0.72	0.23							0.81	0.3	0.51	0.2	0.72	0.27
Cl					0.5	0.13	0.39	0.14			0.38	0.15		
K	2.96	0.96	1.88	0.68	1.31	0.33	2.2	0.82	1.91	0.72	2.11	0.83	2.44	0.91
Ca	48.73	15.73	43.42	15.65	51.11	12.77	42.75	15.81	51.15	19.21	50.55	20.02	45.09	16.84
Ti	1.55	0.5	1.78	0.64	1.69	0.42	1.71	0.63	1.45	0.54	1.62	0.64	1.61	0.6
V													0.04	0.02
Cr													0.01	0.01
Mn	0.48	0.16	0.49	0.18		0.12	0.44	0.16	0.39	0.15			0.51	0.19
Fe	18.26	5.89	24.99	9.01	0.48	6.43	23.73	8.77	18.45	6.93	19.7	7.8	22.24	8.3
Sr					25.72		0.46	0.17	0.31	0.12	0.44	0.18	0.44	0.17
Ag	0.54	0.17	0.82	0.3	1.09	0.27	0.86	0.32	0.8	0.3	0.7	0.28	0.75	0.28
Al2O3	8.06	3.13	7.91	3.37	5.61	1.61	8.87	3.89	7.02	3.14	7.89	3.7	7.98	3.54
SiO2	32.28	12.54	32.19	13.73	22.92	6.57	32.38	14.19	30.76	13.78	28.85	13.52	31.45	13.95
SO3	1.2	0.47			0.36				1.37	0.62	0.87	0.41	1.21	0.54
Cl					1.08	0.1	0.26	0.11			0.26	0.12		
K2O	2.26	0.88	1.45	0.62	46.1	0.31	1.69	0.74	1.48	0.66	1.64	0.77	1.88	0.83
CaO	40.55	15.75	36.9	15.74	1.68	13.21	36.12	15.83	43.14	19.33	43.12	20.21	38.03	16.87
TiO2	1.4	0.55	1.66	0.71	0.36	0.48	1.58	0.69	1.33	0.59	1.51	0.71	1.48	0.66
V2O5													0.04	0.02
Cr2O3													0.01	0.01
MnO	0.33	0.13	0.34	0.15		0.1	0.31	0.14	0.27	0.12			0.35	0.16
Fe2O3	13.62	5.29	19.09	8.14	21.23	6.08	18.05	7.91	14.01	6.28	15.19	7.12	16.88	7.49
SrO							0.28	0.12	0.19	0.08	0.27	0.13	0.27	0.12
Ag2O		0.11	0.45	0.19	0.66	0.19	0.47	0.21	0.44	0.2	0.39	0.18	0.42	0.18
C3S	157.30	61.12	174.86	74.55	236.43	15.66	184.44	80.84	129.25	57.88	120.93	56.68	165.40	73.37
C2S	26.12	10.16	39.63	16.88	112.65	7.02	46.31	20.31	9.32	4.16	8.51	4.00	34.61	15.36
C4AF	41.45	16.10	58.09	24.77	64.60	18.50	54.93	24.07	42.63	19.11	46.22	21.67	51.37	22.79
C3A	-1.69	-0.66	-11.34	-4.84	-21.05	-6.02	-7.04	-3.08	-5.10	-2.30	-4.79	-2.24	-7.41	-3.29
C3S/C2S	6.02	6.02	4.41	4.42	2.10	2.23	3.98	3.98	13.87	13.93	14.20	14.17	4.78	4.78
C3A/C2S	-0.06456	-0.06461	-0.2861356	-0.2869244	-0.186906	-0.8578051	-0.1519105	-0.1514418	-0.5473563	-0.5545015	-0.5629557	-0.560366	-0.214216076	-0.214338642
C4AF/C2S	1.59	1.59	1.47	1.47	0.57	2.64	1.19	1.19	4.57	4.60	5.43	5.42	1.48	1.48

3.1.2 The elements contained atomic energy and dynamic viscosity.

The comparison of elements and dynamic viscosity between exposed roof tiles produced in 2016 and damaged roof tiles are presented in Table 3.

Table 3. Dynamic viscosity.

Atom Energy, keV	Dynamic Viscosity, keV							
	Exposed	Exposed stock	Exposed flat	Unprotected Project	Protected	Exposed	Protected stock surface damage	Gresik cement
	2016	2019	2018	2020	2019	2021	2019	Nov 21
		1	2	3	4	5	6	7
AlKA, 1.5	60	70	30	60	60	50	55	20
SiKA 1.75	500	550	350	580	400	500	580	180
SrLA 1.75				150	200	500	150	
Sr LB 1.9				40	50	50	40	
S KA, 2.3	100				130	90	100	150
Cl KA, 2.7			160	110		50		
Ag LA, 2.9	800	800	1000	800	900	760	800	600
Ag LB1, 3.1	500	400	600	550	400	400	400	280
Ag LB2, 3.3	450	280	220	300	300	300	300	180
Ca KA 3.7	4450	4200	4000	4050	4750	4700	4200	7000
Ca KB, 4	660	610	600	620	700	700	650	1000
Ti KA, 4.5	140	160	130	160	120	120	130	20
Ti, KB, 4.95	40	40	50	40	20	40	30	10
U KA, 4.95							20	
U KB, 5.45							20	
Cr KA, 5.45							20	
Cr KB, 5.9							70	
Mn KA, 5.9	80	80	80	40	60		70	
Mn KB, 6.5	400	450	400	500	400		400	
Fe KA, 6.4	1000	620	1150	1300	980	1100	1200	220
Fe KB, 7.1	200	220	200	240	200	200	200	30
K KA/ K KB	0.65	0.509	1	1	0.5	1	0.5	0.2
Ca KA/Ca KB	6.7	6.9	6.7	6.5	6.8	6.7	6.5	7
Ti KA/Ti KB	3.5	4	2.6	4	6	3	4.3	2
Mn KA/Mn KB	0.2	0.2	0.2	0.08	0.15		0.175	
Fe KA/ Fe KB	5	2.8	5.75	5.4	4.9	5.5	6	7.3

When compared with Gresik cement, there is no Mn content in Gresik cement, while the 2016 production tile contains Mn.

3.1.3 Scanning Electron Microscopy.

The difference in SEM magnitudes of 500 and 5.00 K is presented in Fig. 2-8.

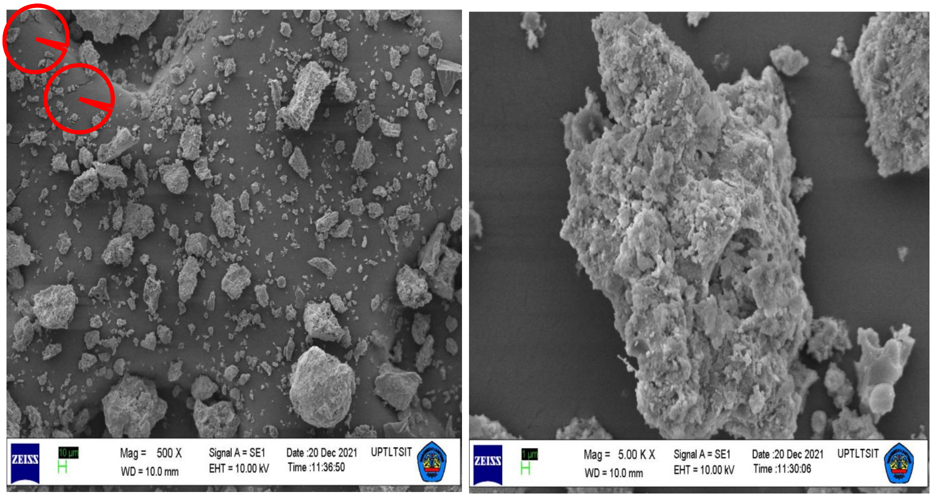
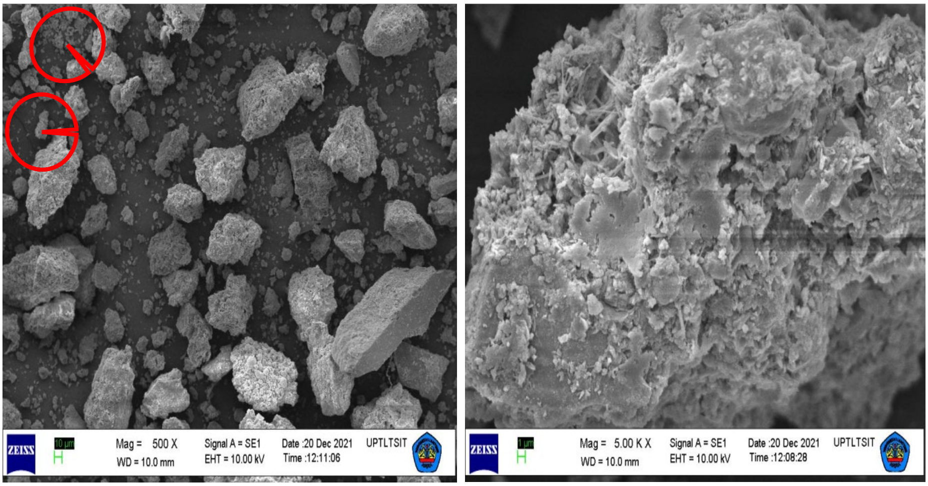
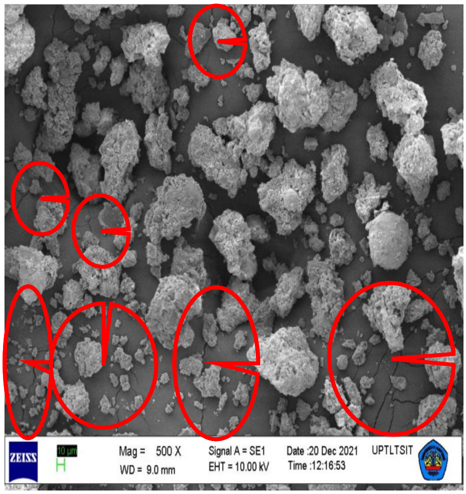


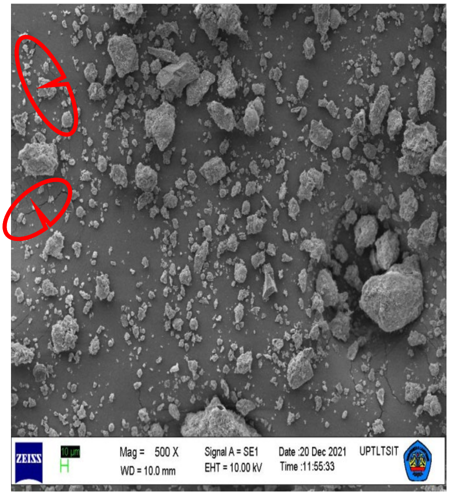
Fig. 2. SEM of roof tile production 2016.



Sample 1: Exposed 2019, S none

Fig. 3. SEM Tile exposed to 2019 production.



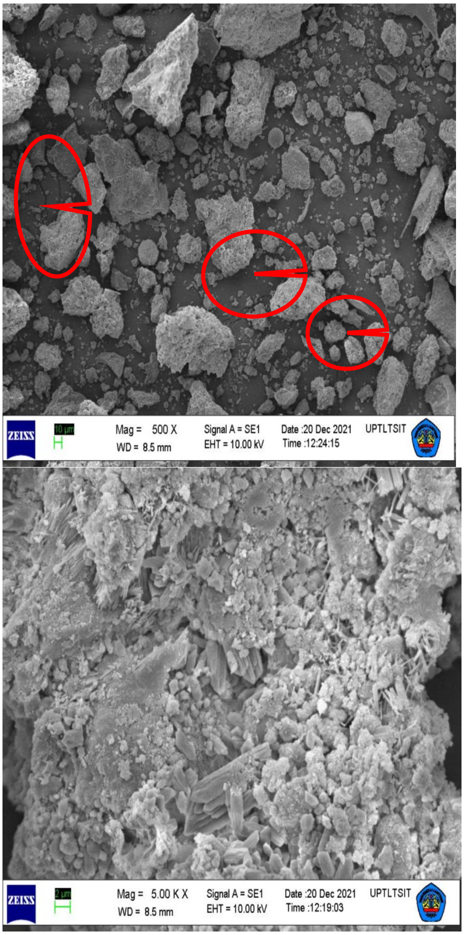


Sample 2: Exposure: S is absent and Cl appears.

Fig. 4. SEM Exposed, flat (mag 500 x).

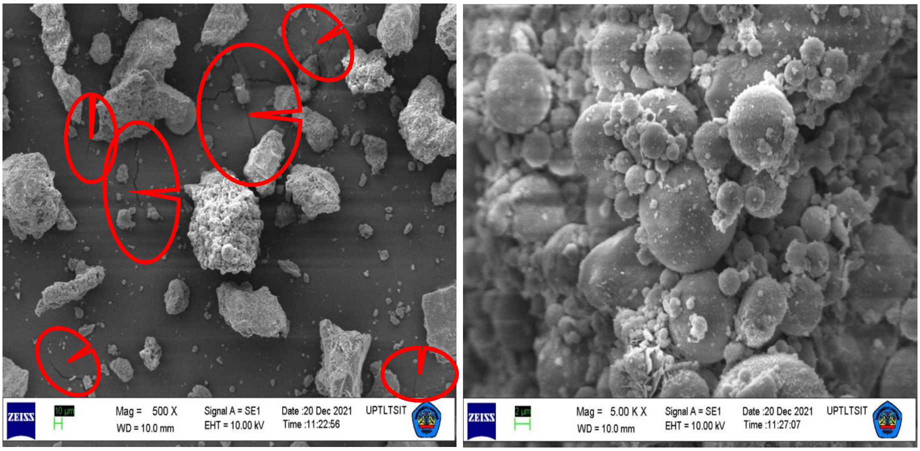
Sample 3: Protected stock 2019: No S; Cl, and Sr appears

Fig. 5 SEM of protected stock, 2019 (mag 500 x).



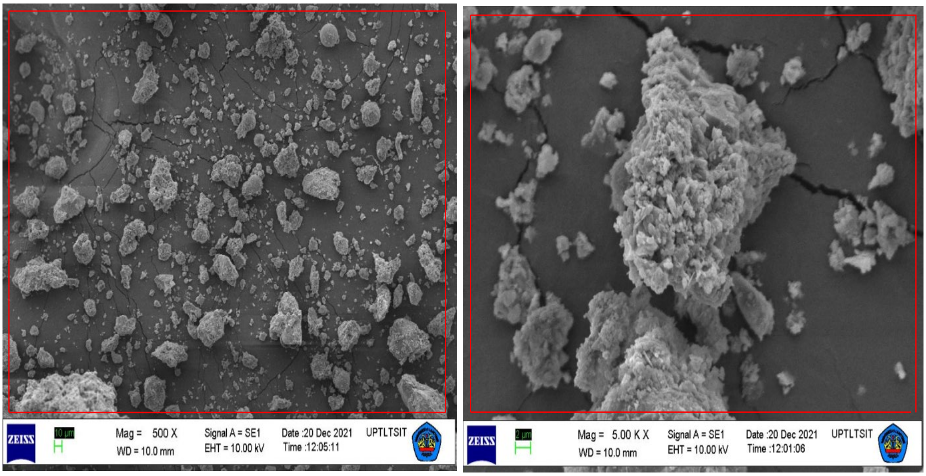
Sample 4: Expose 2020: appearing Sr

Fig. 6. SEM tile exposed, 2020 production.



Sample 5: Exposed: No Mn; Sr, and Cl appear

Fig. 7. SEM of exposed tile.



Sample 6: Broken surface of protected stock: appearing Sr, U, and Cr

Fig. 8 SEM of protected stock, surface damaged.

3.1.4. Merging EDX and SEM results.

The differences in the elements contained in 2016 and damaged roof tiles, as well as the appearance of SEM magnitude 500 and 5.00 K, are presented in Table 4.

Table 4 The differences in the elements contained in the 2016 production roof tiles – damaged tiles, SEM, and C_3S/C_2S appearance.

Sample Code	Different elements of the 2016 production	Magnitude 500 sighting	Magnitude 5.00K sighting	C_3S/C_2S
2016	Al, Si, S, Ag, K, Ca, Ti, Mn and Fe	Number of cracks ±5%, small fractions (1-20), many small ones	Massive, something looks fragile	6.02
1	Lost S (Fig. 3.)	The number of cracks is ±5%, the average fraction is 20, some are solid, some are fragile	More porous, there are flat parts, like needles, which look fragile	4.41
2	Lost S, Cl appear (Fig. 4.)	The number of cracks is±60%, small fractions (1-20), many large ones	Many white lumps, more porous, fragile, porous	2.16
3	Lost S, Cl and Sr appear (Fig. 5.)	Number of cracks ±30%, small fractions (1-20) many small ones	Broken into pieces, white lumps, fragile, porous	3.98
4	Sr appears (Fig. 6.)	Number of cracks ±20%, fraction 5-30	White blobs, rods, needle-like, porous	13.9
5	Lost Mn, Cl and Sr appear (Fig. 7.)	Number of cracks ±30%	Many balls, large and small, are porous, with a few white spots	14.18
6	Sr, U and Cr appear (Fig. 8.)	The whole appearance (100%) cracked, fragments (1-15), many small	Breaks into large pieces and crumbs, porous, white lumps	4.78

The results of the EDX of tile making up materials are presented in Table 5.

Table 5 Elements, ionic energy, and dynamic viscosity.

Element	Atom energy, keV	Dynamic Viscosity, keV				
		Sudamanik ash	Cilegon sand	Suralaya fine ash	Mill ash	Ground water
Sr LA	1.7	198	350	250	200	0
Sr LB	1.8	40	40	40	30	0
Cl KA	2.65	140	225	150	120	1
Si KA	1.75	0	975	800	480	0.5
S KA	2.38	0	0	170	80	0.5
Ca KA	3.65	1620	600	2850	4280	23
Ca KB	4	260	115	430	640	4

All materials for making concrete roof tiles contain Sr and Cl except water.

3.2 Discussion

C_3A/C_2S -0.065 indicates good roof tile quality, while a higher value indicates a fragile tile (Table 2). This means that the value of 2.65 Al_2O_3 – 1.692 F_2O_3 must be small or the amount of Al_2O_3 is very small and the value of C_2S must be large. The formula of C_2S = -(2.867 SiO_2 -0.7544 C_3S) can be replaced with -5.0185 SiO_2 + 3.071 CaO – 5.733 SO_3 – 1.079 Fe_2O_3. If the C_2S value must be large, the SiO_2 value must be large. Negative values for C_3A/C_2S indicate 1.692 Fe_2O_3 > 2.65 Al_2O_3 or 2.867 SiO_2 > 0.7544 C_3S (Table 2).

The increase and decrease of several elements are described as follows:

3.2.1 Increase and decrease of elements.

Increasing or decreasing elements in the concrete roof tile affect the durability of the tile. Testing the reactivity of cement additives is considered necessary to be tested [21]. The addition of a phase changer reduces the overall compressive and flexural strength of the concrete [22]. The reaction of a material to the conditions that occur both within itself or about humidity and temperature can be positive or negative. Material negative reactions can occur at any time without warning. At ambient conditions, concrete roof tiles with cement showed better thermal performance than roofs with extruded polystyrene as insulation material and roofs with false POP ceilings [23]. Tile in Indonesia must be resistant to tropical climates and high humidity with high fluctuation.

3.2.1.1. Sulfur (S). Sulfur is insoluble and does not react with water. Sulfur reacts with almost all other elements except the noble gases, even with the metal iridium which is notoriously unreactive. Some of these reactions require high temperatures [24]. The absence of sulfur (S) in samples 1, 2, and 3 made C_3S/C_2S lower than the 2016 production of 2.1 – 4.4 and became more porous (Table 4, Fig. 2.2, 2.3, and 2.4). According to Tjaronge in Hartini, 2013 [25] the C_3S/C_2S range is 1.5 – 6.5. C_3S/C_2S 6.02 indicates good roof tile quality (Table 4), so the elements SiO_2, CaO, SO_3, Fe_2O must be made in such a way that these indications are met.

3.2.1.2. Strontium.
Strontium (Sr) is contained in all materials for making roof tiles (Table 5). Strontium in its elemental form occurs naturally in many environmental compartments, including rock, soil, water, and air. Strontium compounds can move through the environment fairly easily because many compounds are soluble in water. Strontium reacts strongly with water and tarnishes rapidly in the air, so it should be kept out of contact with air and water [26]. This is in accordance with the results in Table 2 where Sr appears on all protected roof tiles and is not contained in unprotected roof tiles but both were fragile. The presence of Cl and Sr makes the roof tile very easily destroyed even with very little force. The same condition also occurs in roof tiles containing Sr, U, and Cr.

Due to its extreme reactivity to air, this element always occurs naturally in combination with other elements and compounds. Samples 3 to 6 all appear Sr. SEM on a roof tile containing Sr appears fragile and porous (Fig. 3 and 4). Strontium in the soil is soluble in water, so it will most likely move deeper into the soil and groundwater. Samples 1 and 2 did not contain Sr (Table 3).

3.2.1.3. Chlorine. Chlorine is highly reactive and a strong oxidizing agent, can oxidize water to oxygen and hydrochloric acid boils at 34.0 °C [27]. The temperature in Indonesia reaches 34°C on several days in a month [16], so there is a possibility of chlorine boiling. This adds to the brittleness of the concrete tile. Samples 2, 3, and 5 showed Cl, the SEM appeared to have white spots (Fig. 4.). In samples where Cl and Sr occur, the SEM form is fragmented (Fig. 5.).

3.2.1.4. Manganese (Mn). Manganese is a hard, brittle, easily oxidized silvery metal often found in minerals in combination with iron. Manganese increases strength, workability, and wear resistance. Manganese oxide is used as an oxidizing agent, like a rubber additive, in the manufacture of glass, fertilizers, and ceramics [28]. Concrete is a kind of ceramic. The presence of Mn makes there a fragile part of the SEM of 2016 roof tile production (Fig. 2.). In the absence of Mn, SEM looks like balls with sizes from large to small (Fig. 7.).

3.2.1.5. Titanium (Ti). In 2016 roof tile production, there is a Ti element of 1% (Table 2). The mortar strength test showed that the compressive strength was reduced by more than 50% for the 2.5 wt.% TiO_2 content in the slag. On day 28, the compressive strength loss was still more than 40% [29].

*3.2.1.6. Kalium.*The K KA/K KB of ± 0.65 indicates good roof tile quality (Table 3). KB and KA notations show the effect of $C\alpha_{sI}$-, β- and k-Casein Polymorphs on element stability [30].

3.2.1.7. Uranium dan Chromium. In protected roof tiles with damaged surfaces (Sample 6), there are elements of uranium and chromium (Table 3). Uranium occurs naturally in soil, rocks, and in the water, thus the roof tile is in such an environment. Uranium isotopes are unstable and radioactive [31] causing the roof tile surface to be damaged, and microscopically it appears cracked in all parts (Fig. 8.).

Chromium is extremely hard. Its Mohs hardness is 8.5, which means that it can scratch samples of quartz and topaz [32]. Because of its hardness, Cr is able to tear the roof tile so that many cracks appear (Fig. 8.).

3.2.2 Cement.

Portland Pozzolan Cement (PPC) will be used in the production of roof tiles. Only SO_3 (maximum 6%) and MgO (maximum 4%) are chemical compounds that are limited in amount [33]. The mixed pozzolan may contain Sr. The higher the pozzolan mixed in the cement, the higher the probability that the cement contains Sr.

Composite Portland Cement (PCC) is defined as a hydraulic binder resulting from grinding together portland cement slag and gypsum with one or more inorganic materials, or the result of mixing portland cement powder with other inorganic powders. The inorganic materials include blast furnace slag (blast furnace slag), pozzolan, silicate compounds, and limestone, with a total inorganic content of 6% - 35% of the mass of composite portland cement [34]. The desired SrO concentration in industrial blast furnace slag (GGBS) mixed with different additives is 2% [29]. Thus, the use of PCC will increase the content of Sr.

The cement used during the production of fragile roof tiles may contain Sr.

4. Conclusion

The conclusions obtained from the description above are:

- Before 8 months, the roof tile is installed neatly, the fragile ness process occurs but the deformation due to fragile ness has not caused any problems
- Uranium-containing environment causes the roof tile surface to be damaged.
- C_3A/C_2S -0.065, C_3S/C_2S 6.02, K KA/ K KB 0.65 indicates good roof tile quality
- The absence of S, Mn, and the appearance of Sr, Cl were found in fragile tiles. This is thought to trigger the fragile ness of the tile which causes non-uniform deformation. The appearance of the roof tile 8 months after the installation became uneven and partially cracked.
- Sr appears on protected roof tiles. High humidity triggers the appearance of Sr and Sr easily reacts with water and air
- It is possible, that the material for making roof tiles has been contaminated so that it contains Sr and Cl, or it could be that the cement used in the period that produced fragile tiles contains Sr so that the Sr limit is exceeded. The Indonesian standard SNI 0096-2007 [17] has no explanation regarding Sr and Cl.
- The humidity of the bending test in Indonesian standard SNI 0096-2007 [14] which is stated to be 40% needs to be reviewed because the lowest humidity in Indonesia is 50% and the average humidity is 72%
- There is a need for further studies to find a formula for making concrete roof tiles with the current material conditions

Alternative workaround:

1. Make the ratio C_3A and C_2S; C_3S and C_2S worth -0.065 and 6.02 respectively
2. It is recommended not to use PCC because one of the components of PCC is blast furnace slag which contains Sr
3. It is necessary to check the content of Sr and Cl in the cement used
4. Choose a material that does not contain Sr and Cl
5. Make the tile waterproof, and coat it with waterproof

Points 2, 3, and 4 require additional costs which will increase the price of materials.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article and there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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