

Research Article

Compressive Strength and Microstructure of Sugar Cane Bagasse Ash Concrete

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Abstract: This study presents the results of an experimental research study on the effectiveness of Sugar Cane Bagasse Ash (SCBA) as a cement replacement material in concrete production. The ordinary Portland cement was replaced with 0, 5, 10, 15, 20, 25 and 30%, respectively bagasse ash, the effect of Sugar cane Bagasse Ash on workability, compressive strength and microstructure of Interfacial Transition Zone (ITZ) of concrete was examined. The results showed that inclusion of Sugar cane Bagasse Ash in concrete up to 20% level significantly enhanced the compressive strength of concrete at all ages; the highest compressive strength was obtained at 5% SCBA replacement level. The ITZ thickness was greatly reduced with increasing the bagasse ash replacement level up to 15%, beyond that the ITZ thickness was slightly increased, however the thickness was still narrower than the normal concrete, it was observed that at 15% bagasse ash replacement level, the interfacial transition zone was homogeneous and there was no gap between the coarse aggregate and the paste matrix.

Keywords: Compressive strength, interfacial transition zone, microstructure, sugar cane bagasse ash, workability

INTRODUCTION

Utilization of agricultural, industrial and agro-industrial by-products in the form of processed ash attracting researchers to explore their potential as cement replacement material or mineral admixture to the properties of concrete at multiple levels. Utilization of established materials such as silica fume, fly ash and ground granulated blast furnace slag has proved as the high performance concrete ingredients. The benefits were mainly derived from presence of high SiO₂ content and amorphous mineralogical character, which caused high strength and stability of the end product (Shafiq *et al.*, 2007; Shafiq, 2004). It happens due to utilization of calcium hydroxide (free lime forms during cement hydration) reacts with the silica content present in the pozzolans and water that forms additional calcium silicate hydrate, which is called secondary gel, hence the compressive strength is enhanced (Janjaturaphan and Wansom, 2010). Since last few years tremendous efforts have been made to increase the use of cement replacement materials in concrete production because the cement production consumes high energy and is responsible for 5% of global anthropogenic CO₂ emission (each ton of cement produces about one ton of CO₂) and their use can also improve the properties of concrete (Fairbairn *et al.*, 2010).

Bagasse is an abundant waste produced in sugar factories after extraction of juice from Sugarcane. The

huge supply of bagasse needs meaningful disposal. In many countries this type of bulky waste usually used as the boiler fuel in the sugar mills. Increasing cost of natural gas and fuel oil resulting high prices of electricity, due to calorific properties of bagasse waste; since last decade it is being used as the principal fuel in cogeneration plants to produce electric power (Frías *et al.*, 2011; Aigbodion *et al.*, 2010). The burning of bagasse as fuel leaves bulk quantity of ash called sugar cane bagasse ash or SCBA. Sugar cane bagasse ash is recently accepted as a pozzolanic material; however, there is limited research data available on the effects of SCBA on the properties of concrete. Therefore, due to lack of research most of the bagasse ash is disposed in the landfills (Chusilp *et al.*, 2009) and only a few studies reported the use of bagasse ash as partial replacement of cement in concrete (Ganesan *et al.*, 2007). Since, there is a continuous increase in the production of sugar worldwide and approximately 1500 Million tons of sugar cane are annually produced all over the world, which leaves about 40-45% bagasse after juice extraction. Therefore, an average annual production bagasse is estimated as 600 Million tons, which is a bulky waste from sugar industry (Goyal and Anwar, 2007). Sugarcane plantations cover one-fifth of the arable land in Sudan, according to WADE report 2004: Sudan has the highest potential among the countries of eastern and southern Africa of producing electricity from bagasse and over 40% of its electricity

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can be produced from bagasse cogeneration (Morand, 2004).

As mentioned above there is limited research available on the utilization of SCBA as cement replacement material, CRM in concrete as compared to other well-known pozzolans such as silica fume, fly ash, ground granulated blast furnace slag and rice husk ash. In order to establish SCBA as an alternative cement replacement material for high performance concrete, many properties of concrete containing SCBA, such as microstructure of Interfacial Transition Zone (ITZ), long term durability and structural properties including bond strength need to be investigated. The principal aim of this research study is to present the results of an experimental study performed to investigate the effect of SCBA on the mechanical properties of concrete as well as microstructure characteristics of ITZ.

MATERIALS

The materials used in this study are: The Ordinary Portland Cement (OPC) type 1 was used in this study it was complying with the requirements of BS 12 (1996) and MS 522: Part 4 (1989). The chemical composition of cement is shown in Table 1. Crushed Granite rocks with a maximum particle size of 20 mm that was employed as coarse aggregate in this study and mining sand with a maximum particle size of 4.75 mm was used as fine aggregate according to BS 812-103.2: 1989. A naphthalene formaldehyde sulphonate superplasticizer in the form of aqueous solution was used as Water Reducing Admixture (WRA) for all concrete mixes.

Sugar Cane Bagasse Ash (SCBA): The SCBA was obtained from Guneid Sugar factory, located in Gezira Province, Sudan. The obtained ash was further ground in a Los Angeles abrasion machine until the particles retained on 45 μm-sieve were less than 5%. The chemical composition of SCBA was determined using X-Ray fluorescence technique, XRF, the results are given in Table 1. The major oxide observed in SCBA is silica (SiO₂), which is about 77.25%, the total summation of SiO₂ + Al₂O₃ + Fe₂O₃ is 87.83%, the calcium oxide, CaO is 4.05%, hence this ash classifies as class F pozzolan according to ASTM C 618 (2009). The X-Ray Diffraction (XRD) analysis of the SCBA shows the amorphous silica formation with traces of low quartz as shown in Fig. 1. The image of ground SCBA is shown in Fig. 2.

Experimental program:

Concrete mixing and casting: A total of 7 concrete mixes were prepared, one of the mixes was made of 100% cement (no SCBA content), denoted by NC and called the reference mix. The remaining 6 mixes were

Table 1: Chemical composition of OPC and SCBA

Oxide	Weight (%)	
	OPC	SCBA
SiO ₂	20.44	77.25
Al ₂ O ₃	2.84	6.37
Fe ₂ O ₃	4.64	4.21
CaO	67.73	4.05
K ₂ O	0.26	2.34
MgO	1.43	2.61
Na ₂ O	0.02	1.38
P ₂ O ₅	0.10	0.59
TiO ₂	0.17	0.58
MnO	0.16	0.27
SO ₃	2.20	0.11
LOI	-	1.40
SiO ₂ +Al ₂ O ₃ +Fe ₂ O	-	87.83

Table 2: Concrete mix proportions

Mix description	OPC	SCBA	CA	Sand	Water	SP
NC	500	0	945	745	190	3
5% SCBA	475	25	945	745	190	3
10% SCBA	450	50	945	745	190	3
15% SCBA	425	75	945	745	190	3
20% SCBA	400	100	945	745	190	3
25% SCBA	375	125	945	745	190	3
30% SCBA	350	150	945	745	190	3

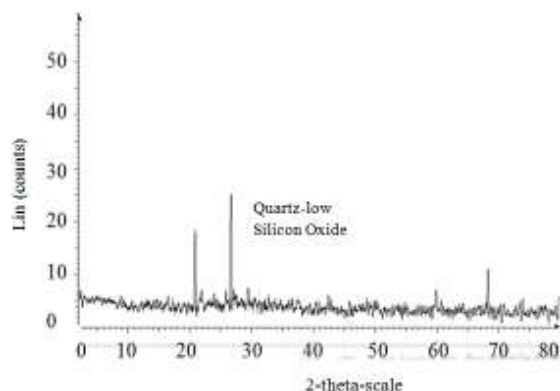


Fig. 1: XRD pattern of SCBA



Fig. 2: Ground SCBA

prepared by adding SCBA content as partial replacement to cement i.e., 5, 10, 15, 20, 25 and 30%, respectively; these mixes are denoted by SCBA content, e.g., 5% SCBA. Details of all mixes are given in Table 2. All concrete ingredients were mixed according to the procedure given in BS 1881-125 (1986), the

superplasticizer dosage was kept constant as 0.6% by weight of cement.

Workability: The workability of the freshly mixed concrete was determined using slump test that was performed according to BS 1881: Part 102 (1983).

Compressive strength: The compressive strength was determined using 100 mm cubes at the age of 7, 28, 90 and 180 days, respectively curing. During compression test, the load on the cube was applied at a constant rate of 3.0 KN/s according to BS 1881: Part 111 (1983).

Interfacial Transition Zone (ITZ): The microstructure of interfacial transition zone of all 7 mixes was investigated using Field Emission Scanning Electron Microscopy (FESEM) technique. For performing this test, a cylindrical core was taken from concrete cube and then a thin slice of about 2-3 mm was cut by the diamond cutter and polished by the electrical polisher for investing FESEM imaging. The ITZ was imaged and its thickness was measured at the same magnification.

RESULTS AND DISCUSSION

Effects of SCBA on workability: Figure 3 shows the slump values for all the concrete mixes. Since the water content and super plasticizer dosage was constant in all seven mixes, therefore, the effect of SCBA on workability of concrete can be better understood. As shown in Fig. 3, the workability of concrete was

linearly increased with the increment in the SCBA content. For reference concrete, NC the slump value was obtained as 160 mm, whereas for 30%, the slump was about 215 mm. It means the addition of SCBA content reduces the water demand in concrete for achieving a desired workability, which is good news for high performance concrete. Although, the particle size of SCBA is much finer than the cement particle but its texture is more glassy similar to that of the fly ash particles, improved workability can be attributed to the low value of LOI 1.4% which indicates the SCBA is completely burned and there is no carbon content in the ash, similar observation was also reported in the available research by others (Cordeiro *et al.*, 2010; Srinivasan and Sathiya, 2010).

Compressive strength: Figure 4 shows the compressive strength of all 7 mixes determined at the age of 7, 28, 90 and 180 days, respectively. At all ages, four mixes containing 5, 10, 15 and 20%, respectively SCBA showed higher compressive strength than the reference mix, NC, whereas mixes 25 and 30% SCBA showed further improvement in strength at the age of 90 and 180 days, which means SCBA has shown good pozzolanic reactivity. At the age of 28 days mixes 5, 10 and 15% SCBA showed 91, 88 and 84 MPa compressive strength, respectively in comparison to 62 MPa, the compressive strength of the reference mix, NC. It is to be noted that reference mix NC has higher slump, while all mixes were having constant water content and dosage of super plasticizer. In case where

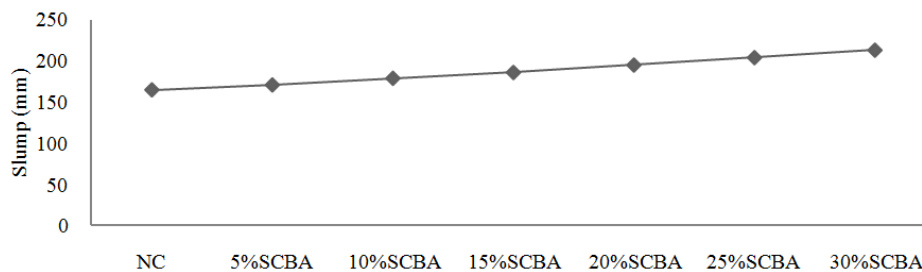


Fig. 3: Effect of SCBA on the workability of concrete

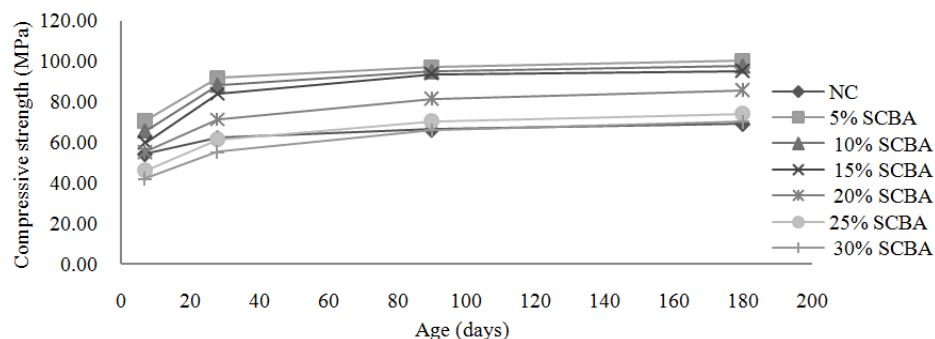


Fig. 4: Effect of SCBA on the compressive strength of concrete

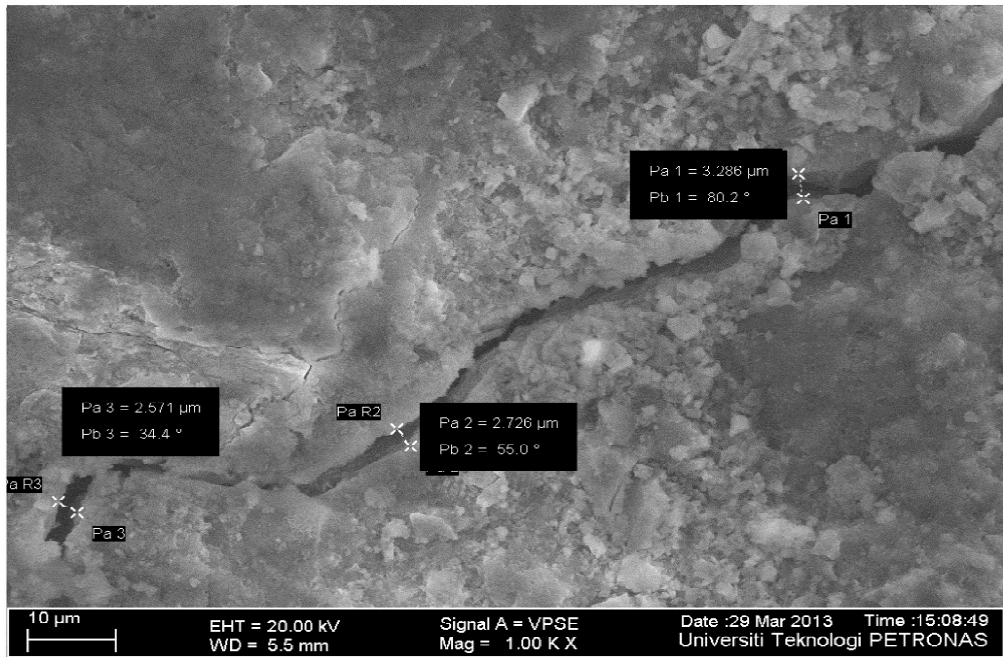


Fig. 5: ITZ thickness measurements

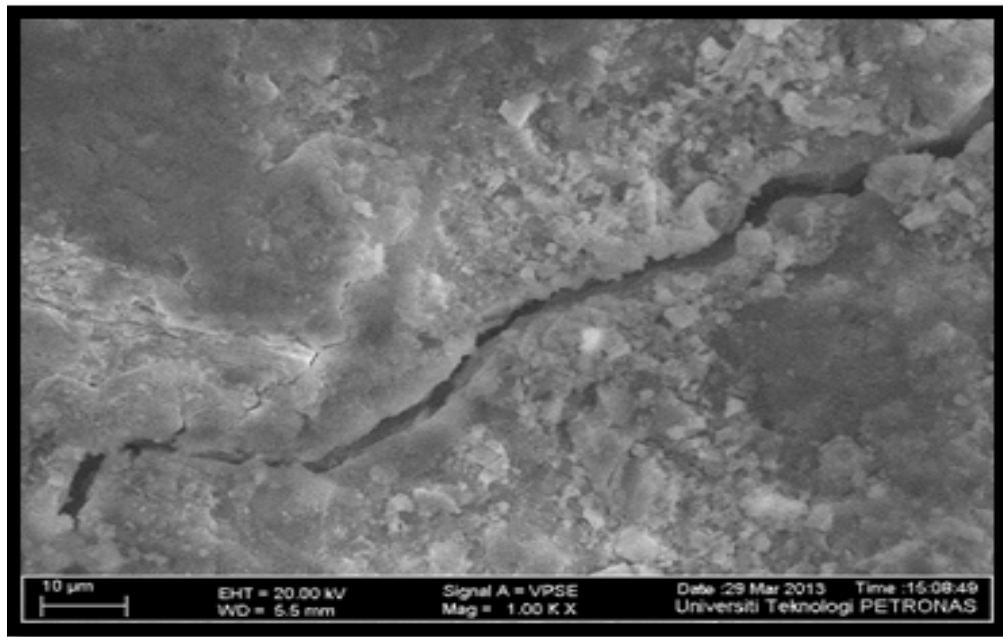


Fig. 6: FESEM image of NC

the workability (slump value) of all mixes to be kept constant, SCBA mixes will require lower water content, hence the compressive strength will be further improved. Twenty five percent SCBA showed similar compressive strength at 28 days as the reference mix achieved, therefore it can be concluded that 25% SCBA mix is equivalent to the reference mix, NC, whereas 5 to 15% SCBA content is determined as optimum replacement for producing high strength concrete.

In general SCBA showed an excellent performance when included in concrete as partial replacement for cement this can be attributed to:

- The high silica content present SCBA that enables pozzolanic reactivity
- Ultra-fine particle sizes in SCBA significantly improve the microstructure that causes high early strength

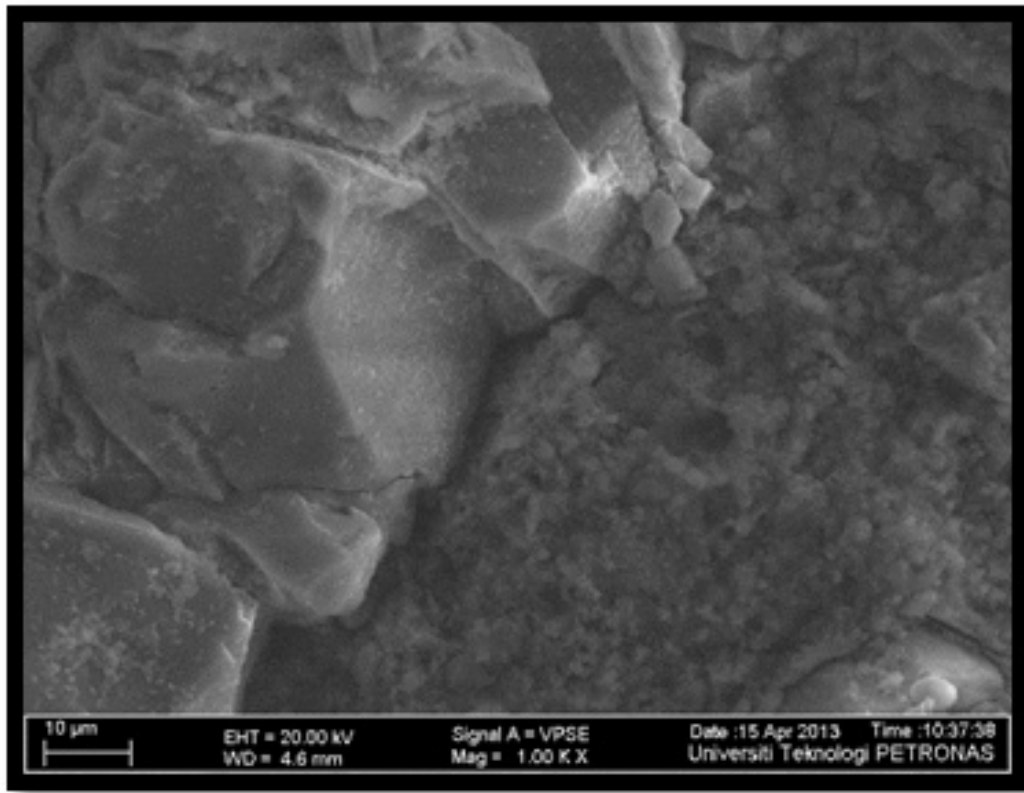


Fig. 7: FESEM image of 5% SCBA

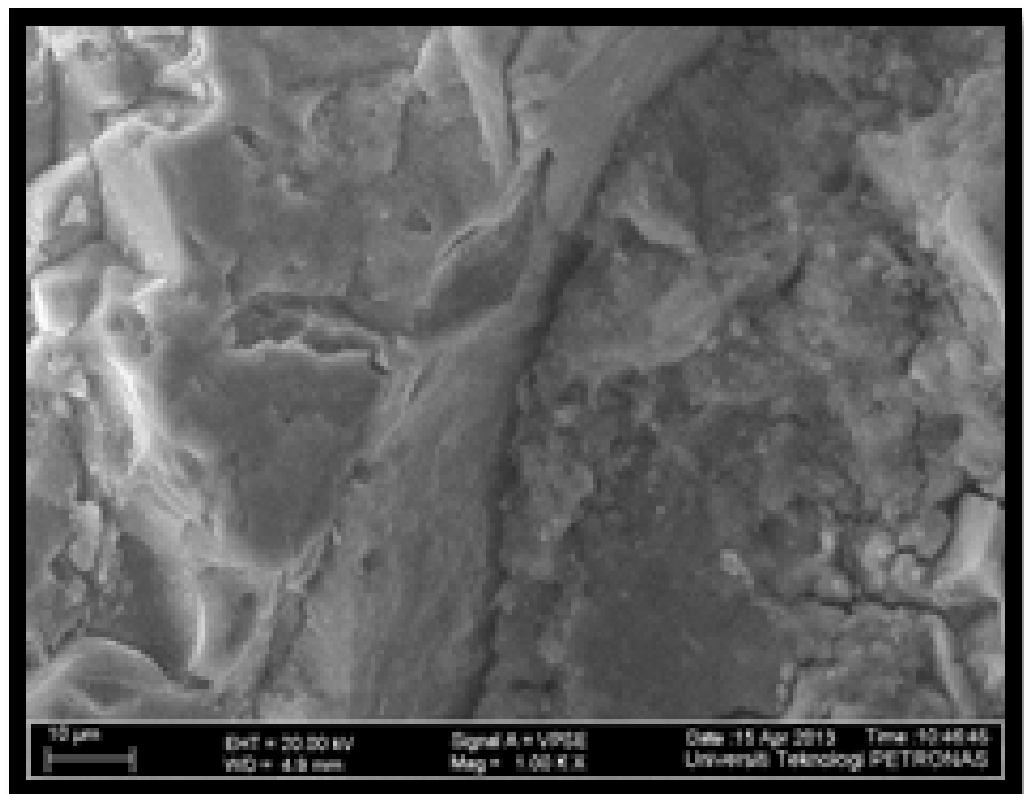


Fig. 8: FESEM image of 10% SCBA

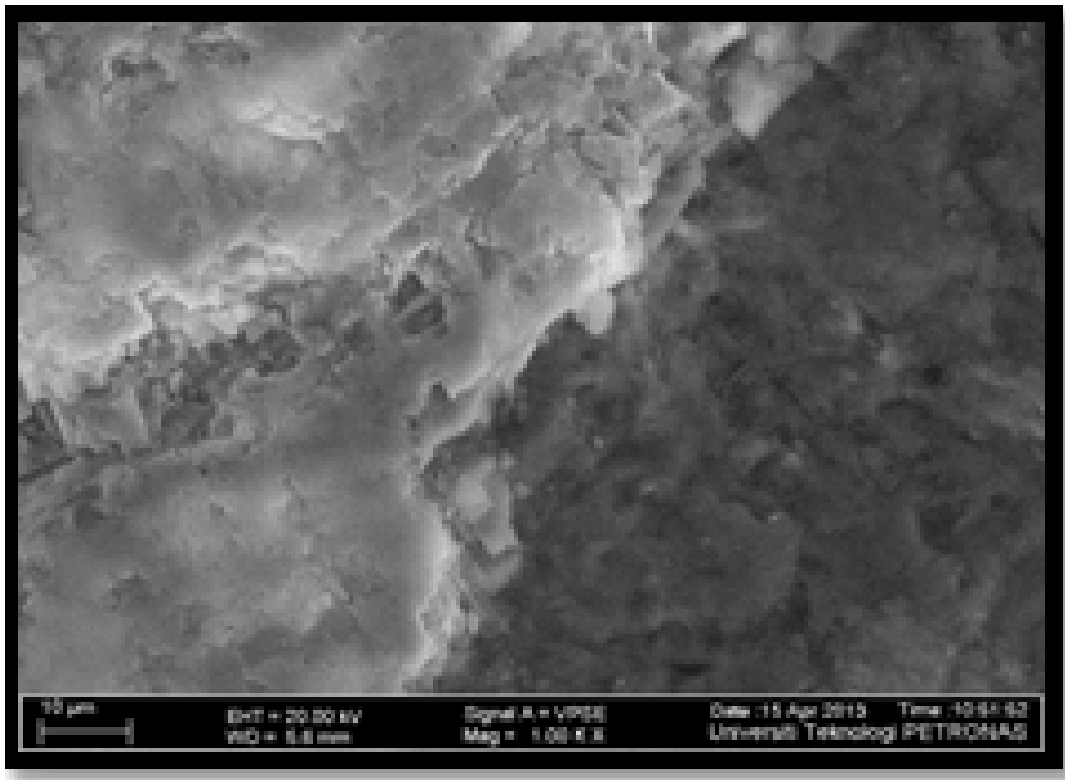


Fig. 9: FESEM image of 15% SCBA

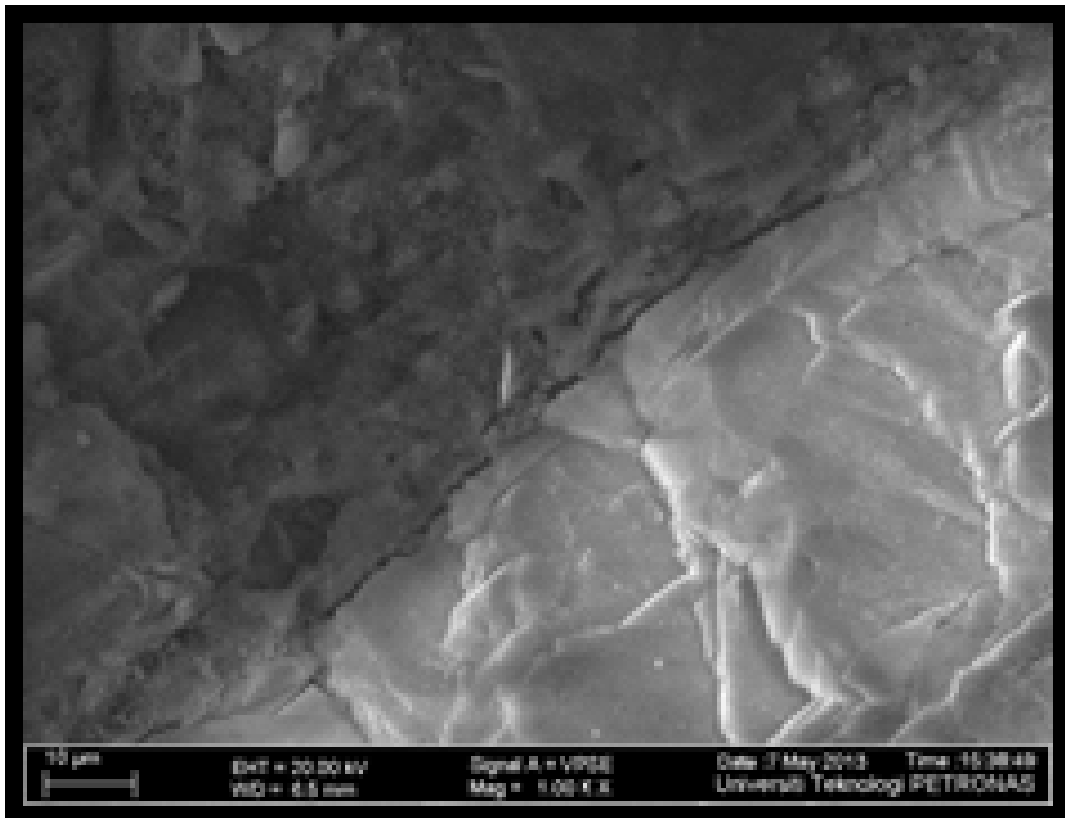


Fig. 10: FESEM image of 20% SCBA

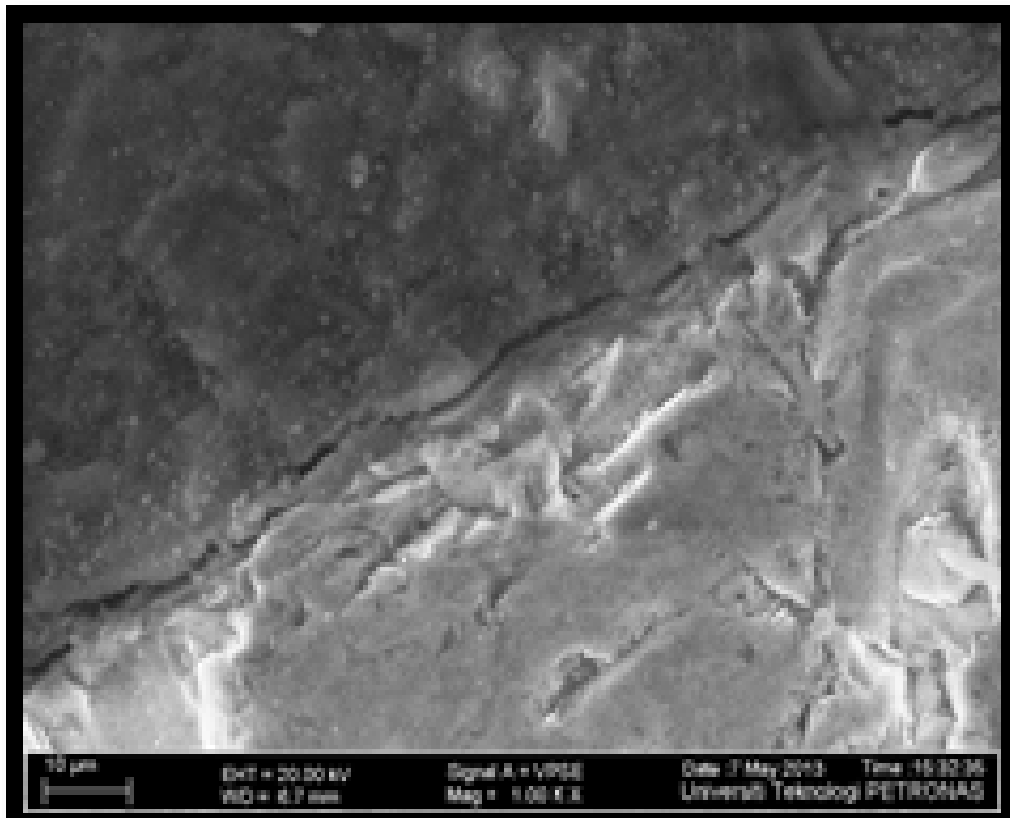


Fig. 11: FESEM image of 25% SCBA

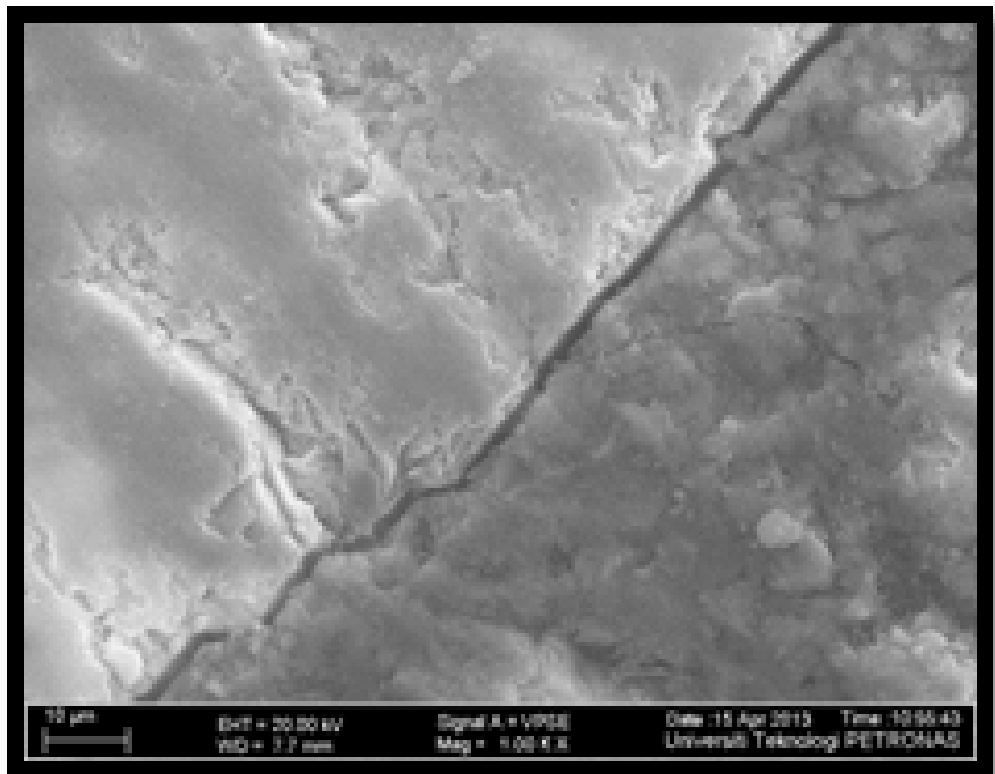


Fig. 12: FESEM image of 30% SCBA

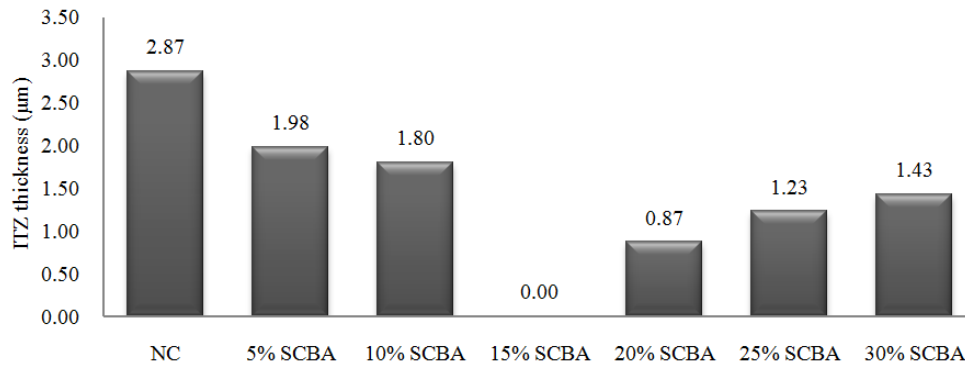


Fig. 13: Effect of SCBA on ITZ thickness

The findings of this study are in agreement with other available researches (Chusilp *et al.*, 2009; Ganesan *et al.*, 2007; Srinivasan and Sathiya, 2010; Suvimol and Daungruedee, 2008)

Interfacial transition zone: Interfacial transition zone, ITZ thickness is defined as the gap length between the aggregate and cement paste in concrete. ITZ thickness was determined to investigate the microstructure characteristics as well as to support the effects of SCBA on compressive and tensile strength. Narrow ITZ thickness results in higher compressive because the bond between aggregate and cement paste become stronger, three ITZ thickness measurements were taken as shown in Fig. 5 and the average ITZ thickness is reported. The FESEM images for all mixes are shown in Fig. 6 to 12. The ITZ thickness in Micrometer is plotted in Fig. 13. It can be observed that the SCBA significantly reduced the ITZ thickness at all replacement levels which strongly confirmed the compressive strength results. The percentage of reduction in ITZ thickness for 5, 10, 15, 20, 25 and 30% SCBA was about 31, 37, 100, 70, 57 and 50%, respectively as compared to the reference normal concrete NC, it is also worthy to notice that at 15% SCBA, Fig. 9, there was no gap to be measured between the aggregate and mortar and the microstructure was very homogeneous, this can be attributed to the pore refinement which led to an improved microstructure at interfacial zone. In general and as it can be observed from, all the SCBA concrete mixes investigated in this study showed a better performance than the normal concrete and increasing the SCBA replacement level in concrete led to increase in the densification of interfacial zone as expected due to its fineness and pozzolanic reactivity.

It was reported by Suvimol and Daungruedee (2008), that the higher the bagasse ash quantity in concrete, the lower the porosity of concrete, this observation can support the improvement of microstructure of ITZ in SCBA concrete mixes in this study as there is no study on the ITZ encountered in the literature.

CONCLUSION

From this experimental study the following conclusions can be drawn.

Addition of SCBA as partial replacement to cement:

- Linearly increase the workability of concrete
- Up to 20% replacement enhanced both the compressive strength at all ages
- Highest 28-day compressive strength was obtained using 5% SCBA replacement which was about 48% higher than the reference mix
- Up to 20% SCBA in concrete is considered as the optimum replacement level
- Twenty five and thirty percent SCBA improved the compressive strength after 28 days
- Inclusion of SCBA in concrete up to 30% significantly improved the microstructure of concrete by reducing the ITZ thickness which indicates better refinement of pore structure and dense matrix compared to the reference mix
- At 15% SCBA level the microstructure of ITZ was totally homogeneous without the presence of wall effect between the aggregate and the paste matrix
- The microstructural properties are strongly related to the compressive strength of concrete
- Further studies on microstructure of ITZ for SCBA concrete are needed as there is no available literature and it is first introduced in this study

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