A COMPARATIVE STUDY ON SEWAGE SLUDGE ASH AFFECTING MECHANICAL PROPERTIES OF GLASS FABRIC/EPOXY COMPOSITES

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ABSTRACT: The effects of sewage sludge ash (SSA) and silicon carbide (SiC) particles on the mechanical properties of S-glass fiber reinforced epoxy composites were investigated. Composite laminate samples for tensile and flexural were prepared and tested according to ASTM standards tests. The results showed that, the tensile and flexural strength were optimum at SSA content of 10 wt% by 8.4% and 33.1% compared to 1.5% and 24.2% with SiC content of 10 wt% and 5 wt%, respectively. Tensile and flexural modulus values of the composites were enhanced compared with the unfilled composite.

Key words: particle, polymer, fiber, mechanical properties.

INTRODUCTION

Polymeric materials have been used for a long time and continue to their important role today. Nevertheless, pure polymers have some limitations such as low strength and stiffness, hence their performance in various fields can be enhanced by adding rigid inorganic fillers in the common matrix resulting in increase of some mechanical properties like strength, modulus, toughness, etc.; furthermore, some of them can provide a significant cost reduction (Fu et al., 2008; Qinghua et al., 2015). Furthermore, particulate polymer composite are often limited from using in automobile, aviation, renewable energy construction and military application, accordingly glass fiber has the advantages of low cost compared to many fibers have been used in fabrication of composite laminates. therefore, using the glass fiber with particulate-filler modified polymer in order to produce cheapest composite laminates having wide applications and superior properties such as high stiffness, strength, thermal stability and resistance to chemical hurt (Sathishkumar et al., 2008; Patnaik et al., 2015). Thus, most polymer matrix has been usually used in these laminate composites is epoxy. Therefore, Epoxy matrix is modified by adding additional components, like thermoplastics (Van et al., 2014) and rubber fillers (Dadfar et al., 2013). For rubber particles, while the phase-separated structure in mixtures often raises the delamination resistance,

the strength and modulus are reduced. Thermoplastics behavior the similar of rubber filler do. Moreover, resin viscosity is greatly increased when high molecular weight thermoplastics are blended with epoxy resin, which causes processing difficulty. In addition, there are important factors strongly affected the mechanical properties of the particulate filled polymer composites, such as interfacial interactions and composite structure. Therefore, the production of good quality composite depends on the homogeneity and compatibility of filler within polymer matrix, which this can reduce the particle aggregation and improve the efficient of particle/matrix interfacial bonding energy and thus mechanical properties (Moczo J and Pukanszky, 2008).

Until most recently, researches focused mainly on rigid particles, like nano-silica, carbon nanotubes nano-clay, and nano-alumina (Wang et al., 2005; Coleman et al., 2006), due to their enhancement for mechanical properties of fiber/epoxy composite laminates. The strength of PEEK/AS-4 composite was significantly improved 12% by adding nano-silica particles of 1 wt% (Jen et al., 2005). Patnaik et al. (2009) found that the addition of FA and SiC micro-particles to glass fiber polyester composites significantly improved the flexural strength by about 10 wt% of FA content, while the tensile modulus increased for both fillers. Wang et al. (2016) raised flexural strength, impact strength values by 16% and 37%, respectively, by adding micro-particle of Al_2O_3 to the carbon fabric/epoxy composite. Bhagyashekar and Rao (2010) indicated that the addition of SiC particles having 44 μ particle size to epoxy was improved the tensile and flexural modulus of the epoxy/SiC composites. Some researchers have been used SSA as an industrial waste filler to improve some mechanical properties like tensile and flexural strength of the composites used for construction application such as bricks and tiles, as a raw materials for cement production, as aggregates for concrete and mortar (Smol et al., 2015). Hence, compared with the earlier studies, the addition of rigid inorganic particulate fillers may be modified for better prediction of the mechanical properties of the composite laminates. Therefore, it is more suitable to study the behavior of mechanical properties for the composite laminates containing micro- and nano-particles.

Population and plants growth increase wastewater in all over the world. Sewage sludge ash is generated during the combustion of dewatered SSA in a burner. SSA is stored and can be used as a filler material. One of the major environmental issues is eliminated some materials can give economical and sustainable solutions. SSA contains compound not harmful to the environments like oxides. The annual amount of SSA is about 3.5 billion m^3 in Turkey (TUIK, 2010). When the 4 percentage of this amount is considered as waste sedimentary, 140 million tons SSA potential is available in Turkey. Sewage sludge incineration system was first developed in Gaziantep (Kütük, 2013). System generates electric by burning approximately 150 tons SSA per day. About 15 tons ash remains at the end of combustion. When the established mechanism is thought as a recycling system the use of remain ash increase the value of mechanism and also use of ash can be

regarded as a versatile earning due to its environmental problem. Applying of the SSA in the fabric/epoxy composites materials was examined in the present study.

Based on the above studies, many of these studies have investigated the flexural and tensile properties of the particulate fillers filled composite laminates. To the best of found knowledge, researchers in literature do not inspected the effect of SSA content on the mechanical properties of S-glass fiber reinforced epoxy (GFRE) composite. In this study, the mechanical properties (flexural and tensile) of GFRE composite were determined with the use of micro size SSA and SiC particles within epoxy matrix. In addition, the SSA and SiC variation of 5, 10, 15 and 20 wt% contents were incorporated with GFRE composites.

MATERIALS AND PROCEDURES

Materials

Epoxy (MOMENTIVE-MGS L285) and hardener (MOMENTIVE-MGS H285) were mixed with a weight ratio of (1/0.4) in the production of composite plates. Woven plain S-glass fiber with areal density of 200 g/m^2 were used as reinforcement fibers in the ply. All above materials were supplied by DOST Chemical Industrial Raw Materials Industry, Turkey. The fillers of SSA and SiC were supplied by Çatalağzı Power Plant, Şahinbey Belediyesi, Gaziantep, Turkey and Eti Mine Works General Management, Turkey, respectively. The particle size of the fillers was measured approximately 1-35 µm for grinded and garbled SSA filler and 35 µm for SiC filler. The bulk densities were measured: 0.72 and 1.49 gr/cm^3 for SSA and SiC, respectively, and their chemical compositions are given in Table 1.

Table 1. Chemical compositions of filler materials.

Filler	Chemical formula/Composition (wt %)
Sewage sludge ash	P_2O_5 (23.56), CaO (19.58), SiO_2 (16.6), SO_3 (8.53), MgO (8.22), Fe_2O_3 (7.46), Al_2O_3 (5.73), K_2O (4.87), ZnO (2.09), TiO_2 (1.08), Cl (0.54), Na_2O (0.44), Cr_2O_3 (0.24), BaO (0.21), CuO (0.19), MnO_2 (0.18).
Silicon carbide	SiC (100).

Composites production and samples preparation.
The composites were prepared by adding particulate SSA or SiC filler in epoxy resin with four different particle contents. The particulate filler quantity was mixed with epoxy with a constant speed of 750 RPM using a mechanical stirrer for 25 minutes to obtain a homogeneous particulate blend. Then hardener was mixed with particulate blend for quick setting of composite. Then, the particulate blend was applied to the fibers layer by layer until all the 16 layers were placed at room temperature 25°C. Afterward, modified laminated fabrics with dimensions of 160 mm×200 mm were subjected to 0.3 MPa pressure in the flat molds for 1 h curing

time with 80 °C temperature. Afterward, laminate were cooled to the room temperature under the pressure (Lamination production process is shown in Figure 1). After the production composite laminates (In this work, the particulate composites will be referred to, for suitability as GFRE-SSA and GFRE-SiC), their sizes were cut to produce tensile and flexural specimens according to ASTM standards. Figure 2 shows the tensile and flexural specimens of GFRE-SSA and GFRE-Si Composites with various particle contents.

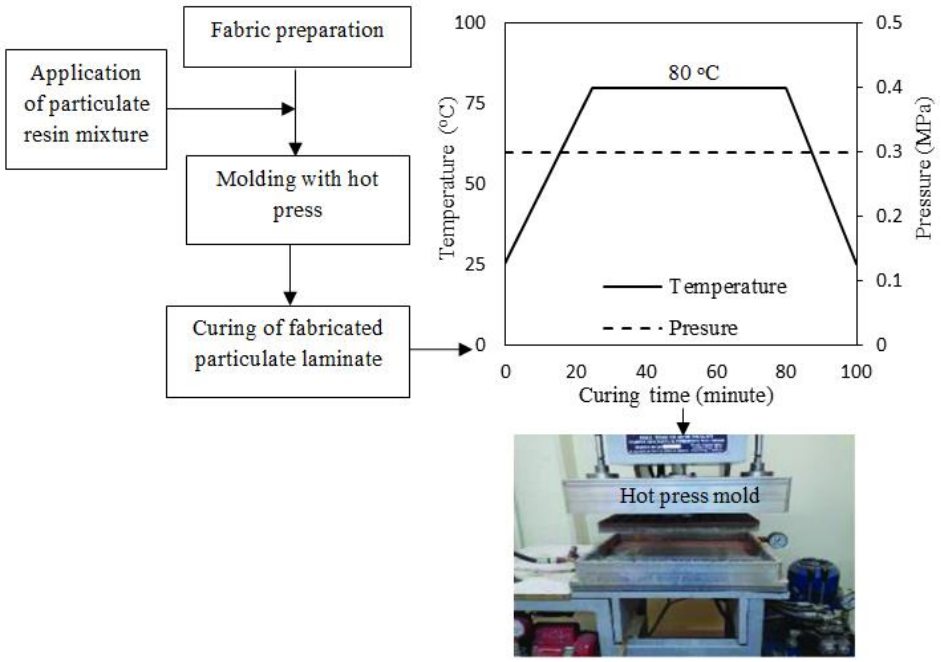


Figure 1. Production process and unit.

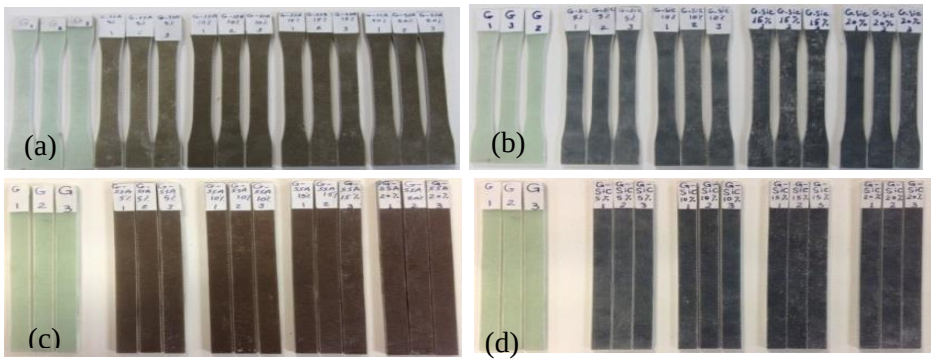


Figure 2. specimens of tensile test: (a) GFRE-SSA, (b) GFRE-SiC composites and flexural test: (c) GFRE-SSA, (d) GFRE-SiC composites.

Tensile and flexural tests

The tensile and flexural properties of the SSA and SiC particle-filled GFRE composite specimens were determined at room temperature using the Shimadzu testing machine AG-X series (Kyoto, Japan) and data acquisition card Ni-9237

(National Instruments Corporation, Austin, TX, USA) configuration (Figure 3). Tensile and flexural test samples were prepared according to the ASTM D 638(2010) in size of 165 × 13 mm for a gauge length of 50 mm and ASTM D 790 (2010) in size of 185 × 12.7 mm with span to thickness ratio of 32:1, respectively. All specimens had thickness in range of 3.4±0.3 mm due to particle content variation. The crosshead speeds for tensile and flexural testing were 2 mm/min and 5 mm/min, respectively. At least three specimens were tested for each composite, and the average value of the output data was depended.

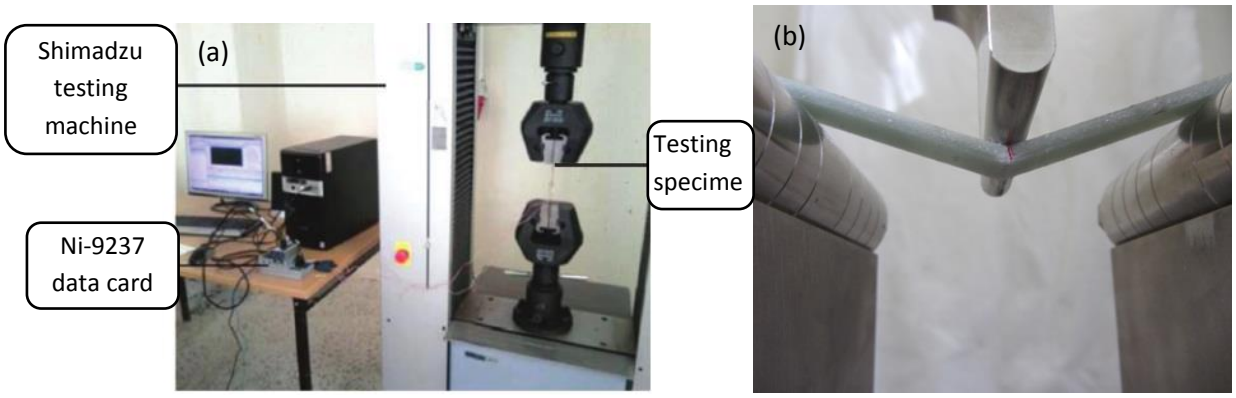


Figure 3. Shimadzu AG-X series testing machine (a) Tensile test, (b) Flexural test

RESULTS AND DISCUSSIONS

Effect of SSA and SiC contents on tensile properties

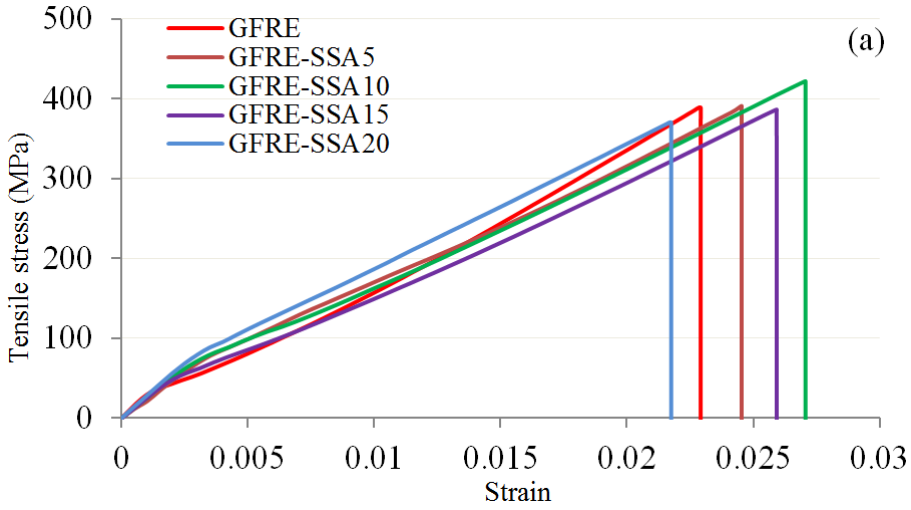
Table 2 displays the tensile properties of GFRE, GFRE-SSA and GFRE-SiC composites for various SSA and SiC filler contents. The tensile tests show a linear response of the elastic and the elastic plastic curves (Figures 4, 5) of the studied particulate composites, as shown in Figure 6, all the fracture surfaces of the samples were flat without any nicking, which means that the samples fail in a brittle manner when they were tested. Moreover, there was no effective permanent decreasing in samples' cross sectional area. Therefore, the samples of particulate composite exhibit a brittle behavior. In addition, whether it was filled or unfilled with SSA or SiC particles, the tensile samples were failed at higher stress. The tensile results show that, for the tested specimens of micro-particle filled GFRE composite, the tensile strength enhanced at 10 wt% content of, SSA and SiC, and then followed the trend of decreasing due to particle aggregation when the SSA and SiC addition above 10 wt%, forming stress concentration and thus weaknesses in the composite strength (Wang et al., 2016; Patnaik et al. 2009). The highest improvement of tensile strength was obtained at 10 wt% content of SSA and SiC with maximum increment of 1.5% and 8.4%, respectively.

Furthermore, the elongation at break decreased with the addition of SiC inorganic solid particles, while it increased with SSA addition due to the chemical compatibility of the SSA is better than SiC with composite system. Hence, the elongation at break improved by 18.2% with SSA addition compared to 4.3% with addition of SiC.

Moreover, as shown in Table 2, tensile modulus has been slightly enhanced by addition of SSA and SiC particles to the GFRE since rigid inorganic particles usually have much higher stiffness values than the organic polymer matrix. Hence, the composite modulus regularly increases with increasing particle content. The highest improvement of tensile modulus is obtained at 10, 5 wt% content of SSA and SiC with maximum increment of 5.2% and 9.4%, respectively, this difference may attributed to SiC particles have rigidity more than SSA particles . The Poison's ratio values of particulate GFRE change randomly with increasing particulate filler content, with slightly decreasing from unfilled GFRE composite.

Table 2. Tensile properties for the GFRE modified by SSA and SiC particles.

Composite type	Filler content (wt%)	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (GPa)	Poison's ratio
GFRE	0	389 (±15)	2.29 (±0.08)	19.1 (±0.62)	0.149
GFRE-SSA_5	5	391 (±11)	2.45 (±0.16)	19.3 (±0.15)	0.147
GFRE-SSA_{10}	10	422 (±16)	2.71 (±0.08)	20.1 (±0.37)	0.142
GFRE-SSA_{15}	15	386 (±14)	2.60 (±0.19)	19.8 (±0.60)	0.141
GFRE-SSA_{20}	20	370 (±8)	2.18 (±0.11)	19.0 (±0.29)	0.139
GFRE-SiC_5	5	374 (±12)	2.11 (±0.07)	20.9 (±0.19)	0.142
GFRE-SiC_{10}	10	395 (±17)	2.17 (±0.12)	20.5 (±0.48)	0.146
GFRE-SiC_{15}	15	354 (±9)	2.39 (±0.16)	20.2 (±0.20)	0.140
GFRE-SiC_{20}	20	344 (±11)	2.23 (±0.12)	19.8 (±0.15)	0.137



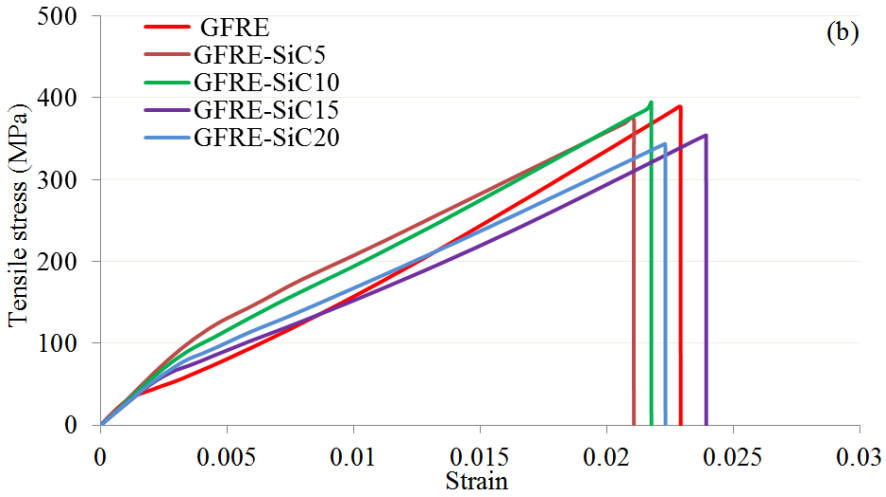


Figure 4. Tensile stress–strain responses for the composites: (a) GFRE-SSA and (b) GFRE-SiC.

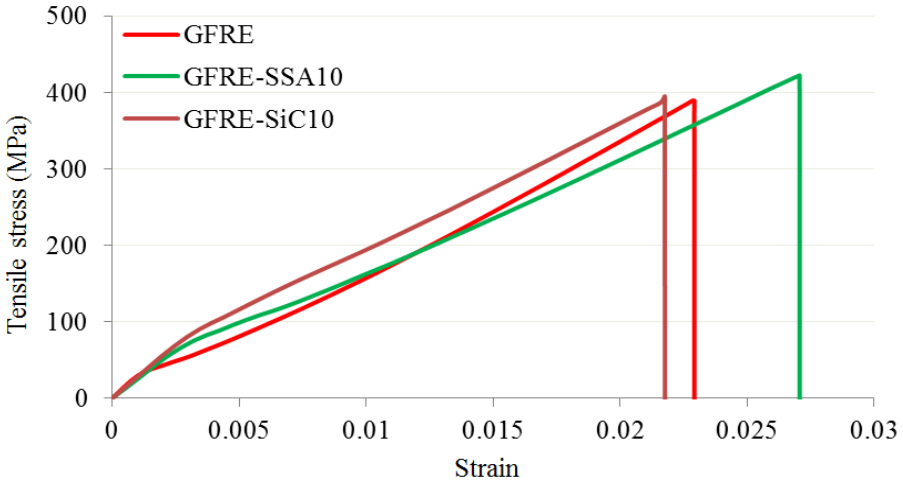


Figure 5. Comparison of tensile stress–strain responses according to composites have maximum strength.

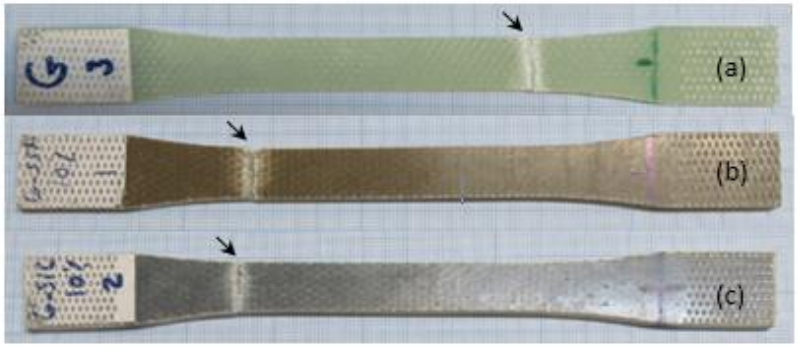


Figure 6. The failed specimens of maximum tensile strength for (a) GFRE, (b) GFRE-SSA and (c) GFRE-SiC composites.

Effect of SSA and SiC contents on flexural properties

The flexural test results are presented in Table 3, all the specimens of the micro-particle filled composite laminates have flexural strength higher than unfilled GFRE composites (Figure 7) Wang et al. (2016). In addition, the flexural strength increased from 410 MPa to 546 MPa when the content of micro-Bx particles changed from 0 wt% to 10 wt%, then further increasing the micro-SSA, the flexural strength reduced to 491 MPa. Same flexural strength trend was observed with addition of SiC particles. Therefore, the maximum increment was 33.1% at SSA content of 10 wt% compared to 24.2% at SiC content of 15 wt%.

The stress-strain responses of the GFRE, SSA-GFRE and SiC-GFRE composites obtained from three-point bending tests are shown in Figure 7. The stress-strain curves exhibited steadily increasing with a linear fashion. In addition, flexural specimens fail at higher stress, for unfilled and SSA or SiC particles-filled composites. In principle, the failure strain values of the GFRE specimens are increased by adding SSA and SiC micro size particles. Hence, the failure strain values increased by 22.5%, and 19.7% at particle content of 10 wt% SSA, 20 wt% SiC, respectively.

Moreover, the flexural modulus relatively improved with SSA micro-particle addition, which it was increased firstly from 2.08 GPa to 2.55 GPa and then decreased to 2.35 GPa, while the flexural modulus of the SiC-GFRE composites was less than unfilled GFRE composites. This behavior is clearly shown in Figure 8, in addition the linearity style of the stress-strain curve for SiC-GFRE composite is less than linearity of the unfilled GFRE and SSA-GFRE curves.

Table 3. Flexural properties for the GFRE modified by SSA and SiC particles.

Composite type	Particle content (wt%)	Flexural strength (MPa)	Failure strain (%)	Flexural modulus (MPa)
GFRE	0	410 (±19)	2.08 (±0.05)	21.0 (±0.32)
GFRE-SSA_5	5	501 (±22)	2.41 (±0.01)	21.6 (±0.85)
GFRE-SSA_{10}	10	546 (±25)	2.55 (±0.09)	21.7 (±0.36)
GFRE-SSA_{15}	15	520 (±9)	2.41 (±0.04)	22.2 (±0.62)
GFRE-SSA_{20}	20	459 (±14)	2.35 (±0.07)	20.9 (±0.14)
GFRE-SiC_5	5	422 (±15)	2.13 (±0.05)	19.3 (±0.40)
GFRE-SiC_{10}	10	440 (±7)	2.20 (±0.08)	18.7 (±0.09)
GFRE-SiC_{15}	15	509 (±16)	2.45 (±0.09)	19.6 (±0.20)
GFRE-SiC_{20}	20	476 (±24)	2.49 (±0.11)	18.1 (±0.75)

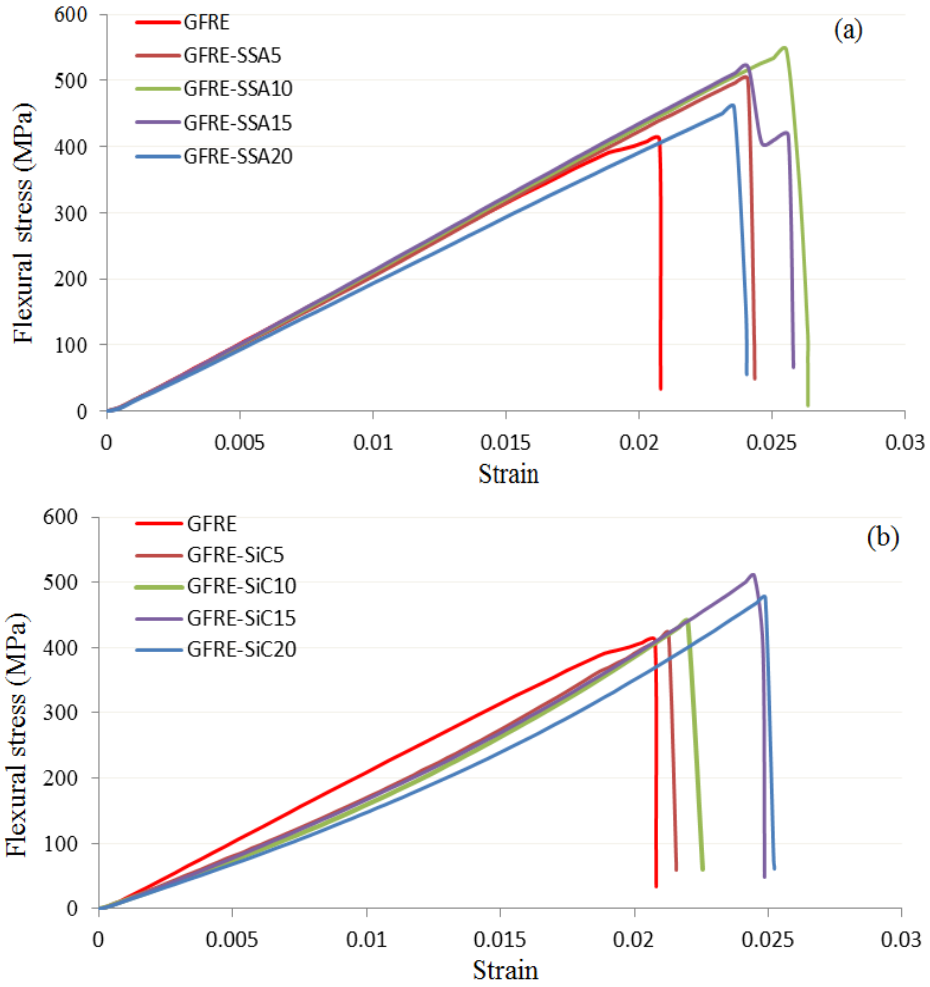


Figure 7. Flexural stress–strain responses for the composites: (a) GFRE-SSA and (b) GFRE-SiC.

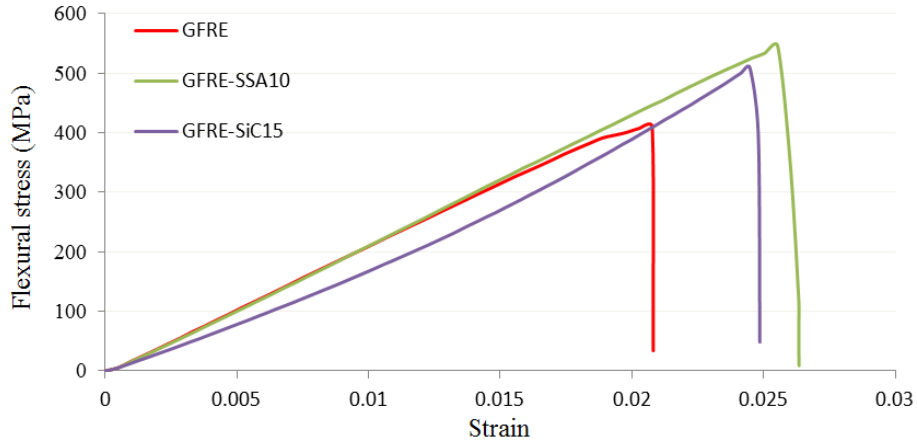


Figure 8. Comparison of flexural stress–strain responses for the composites have maximum strength.

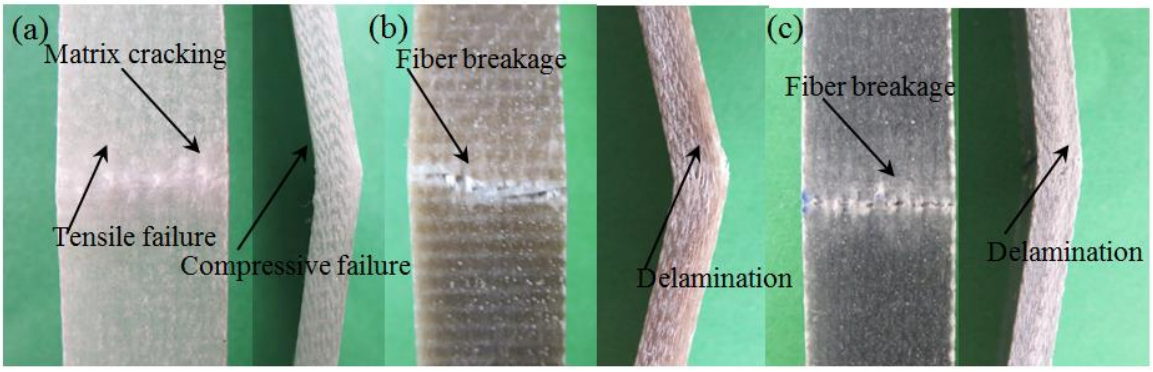


Figure 9. The failed specimens of the maximum flexural strength composites: (a) GFRE, (b) GFRE-SSA and (c) GFRE-SiC.

Flexural damage mechanisms of the GFRE, SSA-GFRE and SiC-GFRE composite specimens were characterized by taking pictures for the tension and side view of the fractured surfaces (Figure 9).The compressive and tensile failures are common failures under flexural loading and they include matrix cracking, fiber breakage and delamination (Davis et al. 2010). The failure of particulate-filled composite in flexural test is dependent on the maximum bending moment that the constituent materials can carry. Representative images for the tension and side view showed all these failure types. The tension views showed clearly the particulate-filled epoxy matrix cracking and the glass fiber breakage. On the other hand, side views illustrated the delamination of glass fiber plies.

CONCLUSIONS

The effects of sewage sludge ash industrial waste and silicon carbide ceramic particles with variation in contents on tensile and flexural properties of the glass fabric/epoxy composites were examined experimentally. The highest improvement of the tensile and flexural strength for GFRE-SSA composites was obtained at 10 wt% content, with a maximum increment of 8.4% and 33.1%, respectively. The tensile and flexural modulus was increased for all the GFRE-SSA composites and the highest improvement was at 10 wt% and 15 wt% content, with a maximum increment of 5.2% and 5.7%, respectively. Generally, the tensile and flexural failure strains of the GFRE-SSA composites were increased. All the above mechanical properties were better than unfilled GFRE and GFRE-SiC composites. Hence, this performance indicates the good adhesion strength and chemical compatibility of the SSA composite system. As a result, due to good mechanical properties and the lower cost of the GFRE-SSA composites, SSA industrial waste can be used as particulate-filler for polymer composites, and this the advantage of this study.

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