Recycling of Sewage Sludge Ash in Polymer Structures

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Abstract-*In this study sewage sludge ash (SSA) particles were used as filler in the polyester resin to fabricate particulate composites with various filler contents of 0, 1, 2, 3, 4, 5, 6 and 7 wt%. The tensile, flexural, impact, hardness, chemical composition and scanning electron microscope tests wear done on the samples in accordance with ASTM standards. The results were improved at the particle content of 5 wt% for the tensile and flexural strength and then showed reducing trend with extra particle addition. Tensile and flexural modulus values of the particulate polyester composites significantly enhanced compared with the unfilled polyester composite. Energy Dispersion Spectrometry (EDS) results showed that the SSA contains elements and oxides which may increase adhesion force with polymer. In spite of the particle content of SSA that used with polymer to produce various structures for different applications was low, this study approved that using of SSA can protect the environment due to increasing the amount of SSA can affect the environment badly in addition to produce cheaper polymer composite for industrial applications.*

Keywords- *Sewage sludge ash, polyester, composite materials, mechanical properties.*

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1. Introduction

Composites of polymer matrix base are used widely in industrial and engineering applications as a result of their high specific strength and stiffness, resistance to fatigue and corrosion, and sound flexibility for design [1-2]. Using particles in order to improve the mechanical performance of the polymer in addition to decrease the composite cost that are used in different applications like industrial and structural field, also, has revealed a focus for significant interest [3-7]. Several researches in recent literature have been studied the improvement of mechanical performance for polymer matrix with inclusion of various kinds of microparticles and nanoparticles. Fu et al. [8] revealed that the mechanical features of particulate polymer composites such as strength, stiffness, impact, etc. have been affected by particle size, shape and loading, also particles dispersion in the composite matrix in addition to adhesion strength between polymer interface and particles. Alsaadi and Erkliğ [9] examined the tensile, flexural and interlaminar fracture with incorporation of SiC and borax particles of glass fiber/epoxy composites. This study displayed that the tensile strength and modulus, flexural strength and modulus in addition to interlinear fracture were enhanced with incorporation of borax particles. In the literature, few studies have been found related with using SSA as an industrial waste filler material in order to improve flexural strength and various other mechanical behavior of the construction industry as an approach towards a circular economy [10-11]. Erkliğ et al. [4] investigated the effect of different particulate filler loadings of SSA, SiC and fly ash on tensile and flexural properties of polyester composite. The study showed that the mechanical properties were improved with using SSA. The SSA was created throughout the combustion of dewatered sewage sludge in a burner and supplied from Şahinbey Belediyesi, Gaziantep/turkey.
According to the above studies, many researches have been explored the incorporation of microparticles and nanoparticles as strengthened fillers for polymer composites like SiO_2, Al_2O_3 and SiC etc. Nevertheless, insufficient researches indicated the additions of SSA within polyester resin and no studies were examined the behavior of tensile, flexural, hardness and effect of polyester composites filled with Iraqi SSA

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particles of different loadings in open literature, therefore, further studies are essential. In this study, the effects of SSA particles content of 0, 1, 2, 3, 4, 5, 6 and 7 wt% filled polyester matrix composites on mechanical behavior are investigated. The mechanical behavior of tensile, flexural, impact and hardness of particulate filled polyester. Energy Dispersion Spectrometry results displayed the elements and oxides of SSA particles.

2. Experimental Work and Tests

I. Materials used in the experimental analysis

Unsaturated general-purpose polyester resin (Polipol 3401-TAB) (Density =1.105 gr/cm3) supplied from the POLIYA Chemical Company, Turkey was used as a matrix. This resin has a perfect accelerator combination with inclusion of 1.0 wt% of methyl-ethyl-ketone-peroxide (MEKP) as a hardener, to give good cure product. The industrial waste filler of SSA were supplied by Al-Rustumya, Mayoralty of Baghdad/Iraq.

II. Fabrication of samples

The samples were prepared using the hand lay-up technique. Samples of SSA/polyester composite with various SSA loadings used in this work were produced by pouring the mixture contain both polyester resin and SSA in a metal mold. To obtain a homogeneous mixture, the measured quantity of SSA like 0.1 wt% was mixed with polyester resin for 15 minutes. Then hardener of 1.0 wt% was added to the mixture to produce the samples. After one day, the samples were taken out from the mold, and then samples were cured for a week arranging to perform mechanical testing.

The samples of tensile, and impact test were prepared with a size of 165 × 13 × 4 mm with a gauge length of 50 mm compatible to standard of ASTM D 638 [12], and for flexural test of D 790 standard with a size of 127 × 12.7 × 4 mm with 16:1 span-to-thickness ratio [13], in addition to Charpy impact were tested following ISO 179/92 standard with size of 55 × 10 mm. The tensile, flexural Charpy impact and hardness samples of various SSA-particle-loading-filled polyester composites are shown in Figure 1.

Figure 1: Tensile, flexural Charpy impact and hardness test samples

III. EDS-Energy Dispersion Spectrometry test

The chemical composition of SSA was obtained using EDS-Energy Dispersion Spectrometry test (Bruker Nano GmbH, Germany). Figure 2 presents the EDS-Spectrum chart of SSA particles. Figure 3 shows the image of SSA particles with particle size between 100-300 µm using Scanning Electron Microscope (SEM) (JEOL JSM-6390 lv, Nahrain University), and their elements are reported in Table 1 and 2. It can be observed in the SEM micrographs, the pozzolanic force can be generated due to chemical composition of SSA, which contains carbon, silicon and alumina in addition to oxides that lead to strengthen the interfacial adhesion force between particle and polyester matrix.

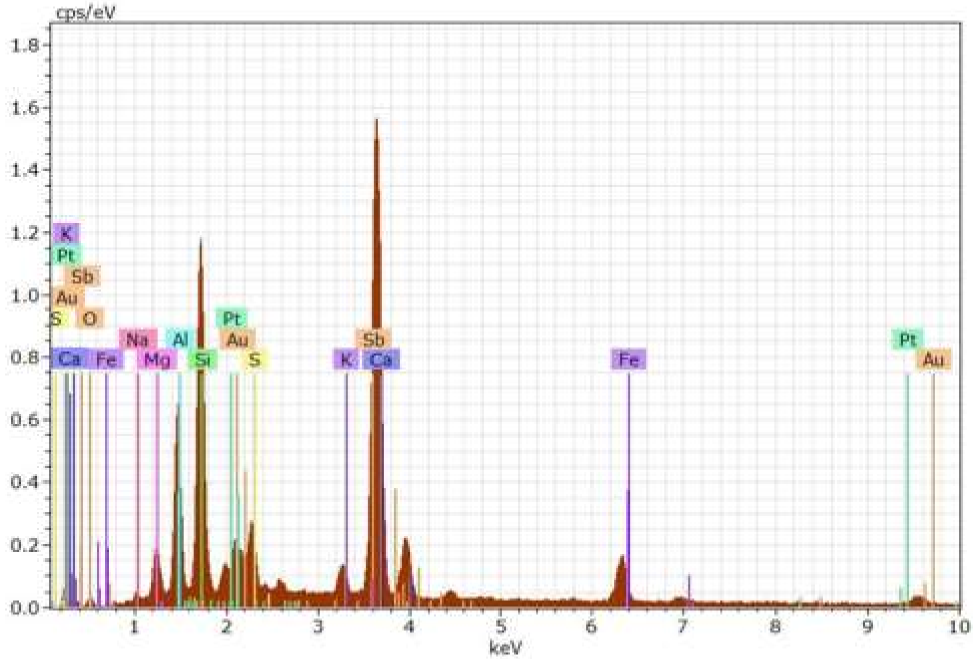

Figure 2: EDS Spectrum of SSA.

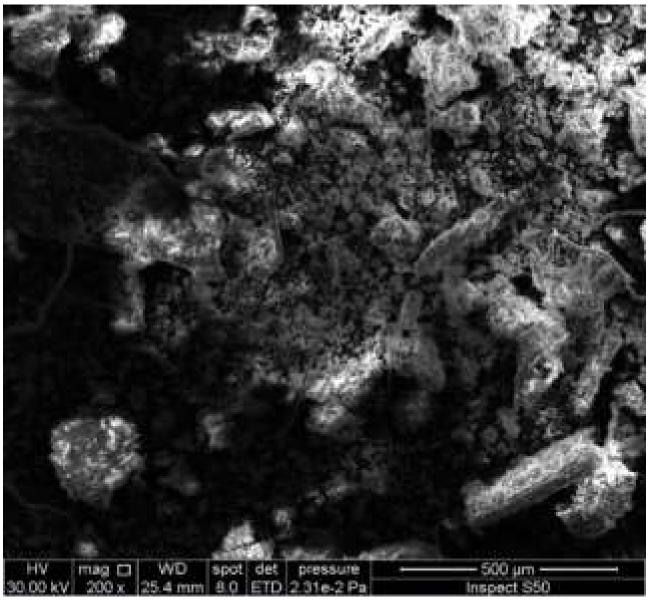

Figure 3: SEM photo of SSA.

Table 1: The Chemical elements of SSA.

Element	AN	series	[wt.%]	[norm. wt.%]	[norm. at.%]	Error in wt.% (1 Sigma)
Carbon	6	K-series	26.55056	27.083	55.99628	4.747203
Antimony	51	L-series	22.11631	22.55983	4.60133	0.693018
Silicon	14	K-series	13.44806	13.71775	12.12948	0.645693
Calcium	20	K-series	12.2218	12.46689	7.724914	0.401219
Aluminum	13	K-series	8.189669	8.353902	7.6889	0.462917
Magnesium	12	K-series	3.333568	3.400419	3.474388	0.252377
Oxygen	8	K-series	2.383718	2.431521	3.774121	0.80874
Iron	26	K-series	2.260207	2.305533	1.02521	0.107315
Sulfur	16	K-series	2.023829	2.064414	1.598798	0.115031
Gold	79	L-series	1.928399	1.967071	0.24801	0.12961
Platinum	78	L-series	1.809106	1.845386	0.234918	0.121479
Potassium	19	K-series	0.981014	1.000687	0.635597	0.067688
Sodium	11	K-series	0.787802	0.8036	0.868054	0.115657
		Sum:	98.03405	100	100	

IV. Tensile and flexural tests

The tensile and flexural tests of particulate SSA/polyester composites were done at room temperature by using (wdw_50:LARYEE) testing machine. The tensile and flexural results were obtained by loading the samples with a testing speed of 1 mm/min. Three samples were examined for every composite's sample of SSA/polyester, and the mean value was considered.

$$\sigma_T = \frac{P_{max}}{bh} \quad (1)$$

$$E_T = \frac{\sigma_T}{\varepsilon_T} \quad (2)$$

$$\varepsilon_T = \frac{\Delta L}{L^2} \quad (3)$$

Where,

σ_T :Tensile strength (M N/m2),E_T: Tensile modulus (M N/m2), ε_T :Tensile strain (M N/m2).

To obtain flexural results, the equations below were used:

$$\sigma_F = \frac{3P_{max}L}{2bh^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{h}{L}\right)\left(\frac{D}{L}\right)\right] \quad (4)$$

$$E_F = \frac{mL^3}{4bh^3} \quad (5)$$

$$\varepsilon_F = \frac{6Dh}{L^2} \quad (6)$$

Where,

σ_T :Flexural strength (M N/m2),E_T: Flexural modulus (M N/m2), ε_T :Flexural strain (M N/m2)

V. Charpy impact test

Charpy impact machine with impact capacity of 5.5 Joule supplied from Time group: China was used to perform the impact tests, in accordance with ISO 179/92 standard. Specimens were produced with a size of 55 mm × 10 mm and span of 40 mm in agreement with ISO 179/92. The unit of absorbed impact energy (H) was used as Joule. The absorbed impact energy and impact strength of the specimens were calculated by these equations:

$$H = H_1 - H_2 \ldots \text{(٧)}$$

$$G = H/(bt) \quad \text{(٨)}$$

Where,

G:impact strength (KJ/m2), b and t: width and thickness of the test specimen, H1 and H2:potential absorbed energies before and after impact.

VI. Hardness test

Shore hardness type (D) instrument (Elcometer, Germany) was used to achieve hardness tests on SSA/polyester composite samples, in accordance with ASTM D2240 standard at room temperature. Cylindrical shape samples with diameter of 40 mm were used to perform hardness tests.

3. Results and Discussion

I. SSA Effects of on tensile characteristics

Figure 4 shows the results of tensile stress-strain for various particle loadings of SSA/polyester composites. The tensile strength was increased with increasing SSA particles. The failure strain was decreased gradually due to particle restraint in the matrix. The elastic limit also improved that led to increase the elastic modulus due to the hard particle of SSA (Figure 5). As seen in Figure 5, the maximum value of tensile strength is reached to 42.8 MPa at 5 wt% of SSA particle loadings and this improvement continued up to 7 wt% hence still larger than unfilled polyester. The elastic modulus continuously increased to become 7.7 GPa at 3 wt% of SSA particle loadings compared to 2.9 GPa for unfilled polyester, then the modulus behavior decreased at 5 wt% then slightly decreased at 6 and 7 wt%. Figure 6 displays the samples of tensile failed specimens of the SSA/polyester composites. It can be noted that the specimens broken in brittle fracture without nicking.

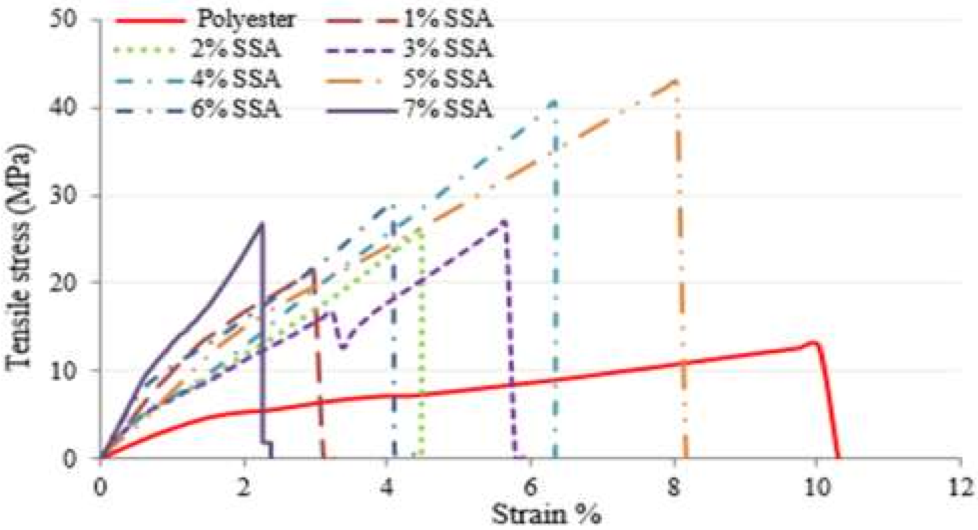

Figure 4: Tensile stress-strain curves for the SSA/polyester composites.

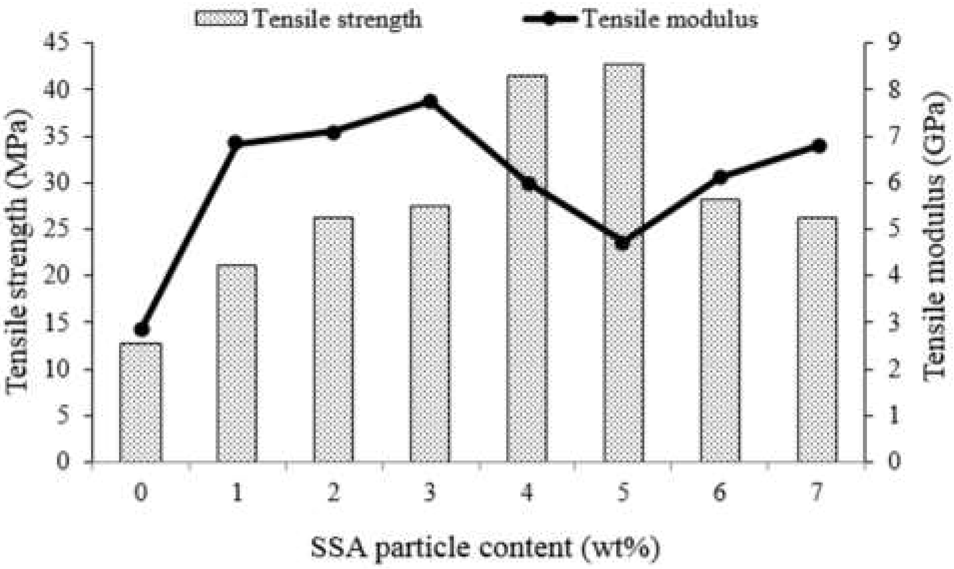

Figure 5: Tensile strength and tensile modulus with respect to SSA particles.

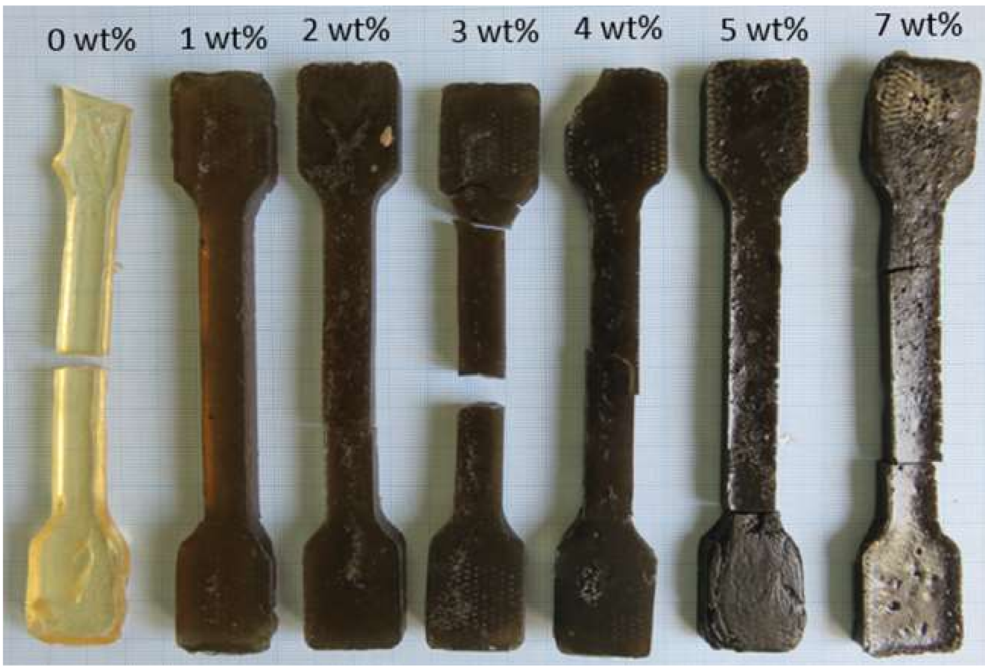

Figure 6: Samples of tensile broken specimens of the SSA/polyester composites.

II. SSA Effects of on flexural characteristics

The results of flexural stress-strain responses of different particle loadings of SSA/polyester composites are illustrated in Figure 7. The flexural strength was improved with more including of SSA particles. The failure flexural strain was decreased gradually with more SSA including due to particle restraint in the matrix. The elastic limit also increased that led to improve elastic modulus due to the hard particle of SSA (Figure 8). As shown in Figure 8, the maximum value of flexural strength is reached to 27.3 MPa at 5 wt% of SSA particle loadings with improvement of 167% compared to 10.2 MPa for unfilled polyester and this behavior continued up to 7 wt% that the flexural strength still larger than unfilled polyester. The elastic modulus continuously increased to become 4.9 GPa at 6 wt% of SSA particle loadings with improvement of 230% compared to 1.5 GPa for unfilled polyester, then the modulus decreased at 7 wt%. Figure 9 displays the samples of flexural failed specimens of the SSA/polyester composites. The specimens were broken in brittle fracture.

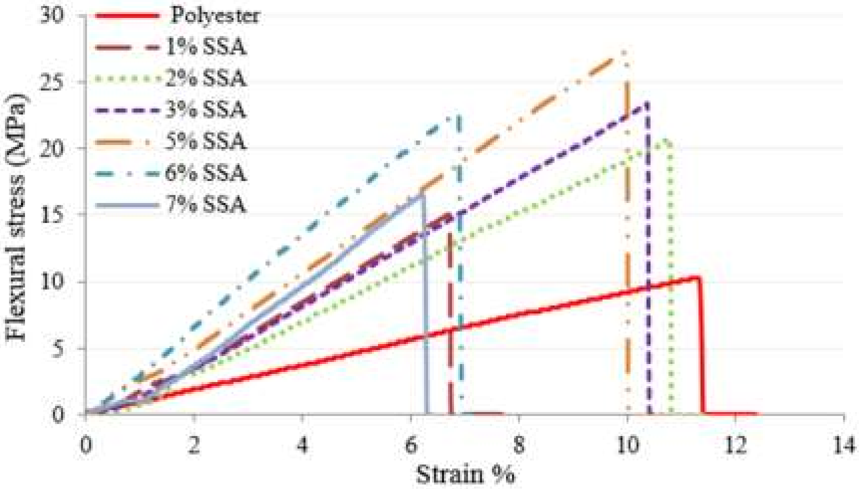

Figure 7: Flexural stress-strain curves for the SSA/polyester composites.

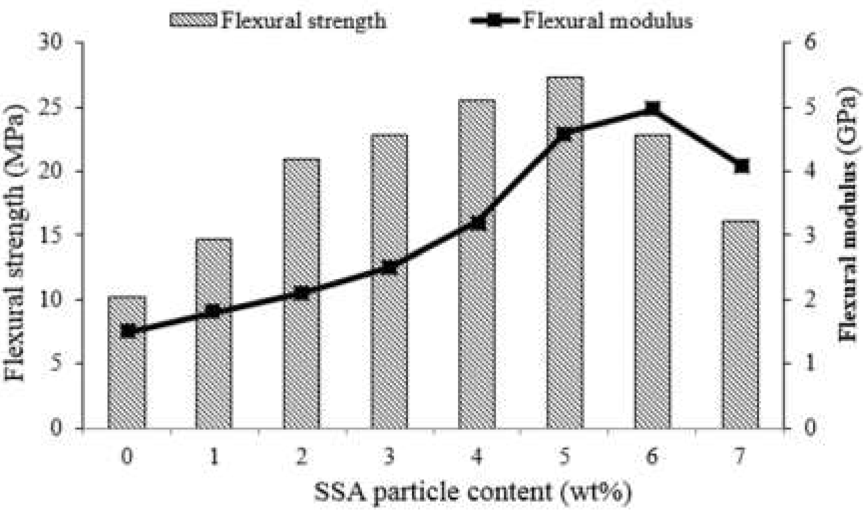

Figure 8: Flexural strength and tensile modulus with respect to SSA particles.

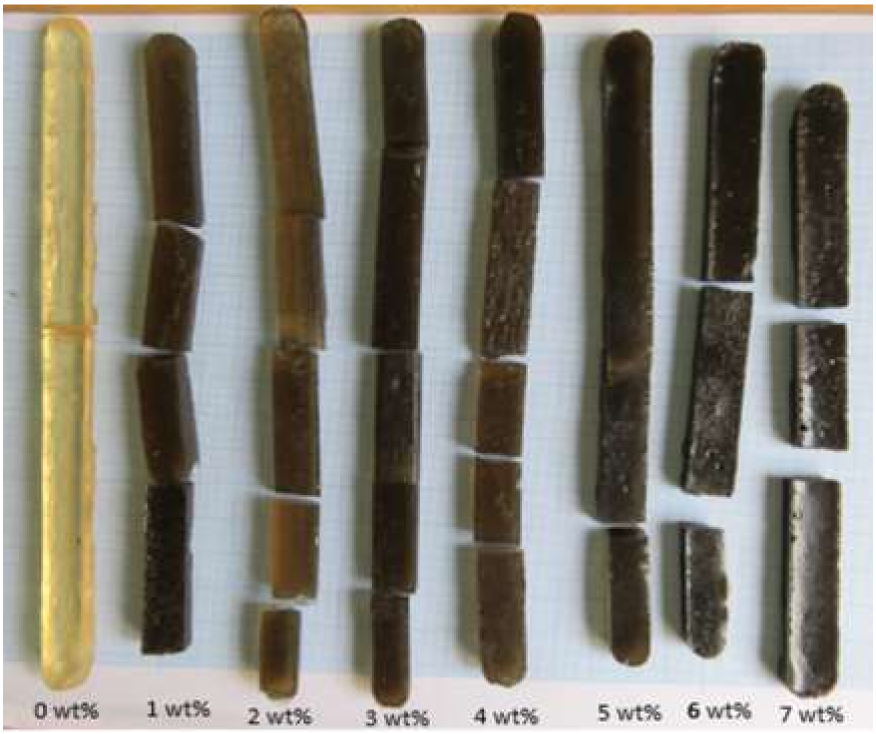

Figure 9: Samples of Flexural broken specimens of the SSA/polyester composites.

III: SSA affects of on Charpy impact characteristics

The impact strength and absorbed energy for the SSA/polyester composites are shown in Figure 10. The Charpy impact properties were improved with addition of SSA to polyester matrix. The impact absorbed energy was reached to 0.38 KJ/M2 and the largest impact strength was 5.4 KJ/M2 at 5 wt% of SSA particle loadings with improvement of 153% compared to unfilled polyester then decreased. Figure 11 shows the failed samples of Charpy impact test of the SSA/polyester composites. The specimens were broken in brittle nature.

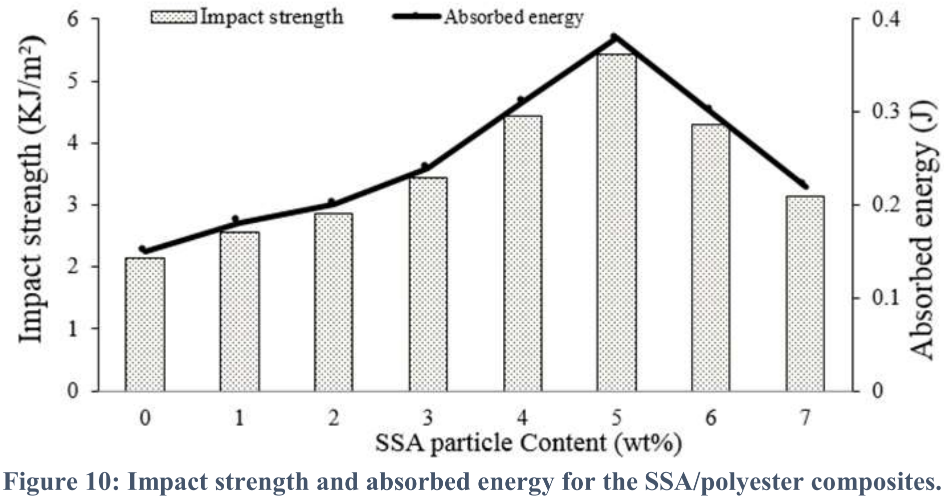

Figure 10: Impact strength and absorbed energy for the SSA/polyester composites.

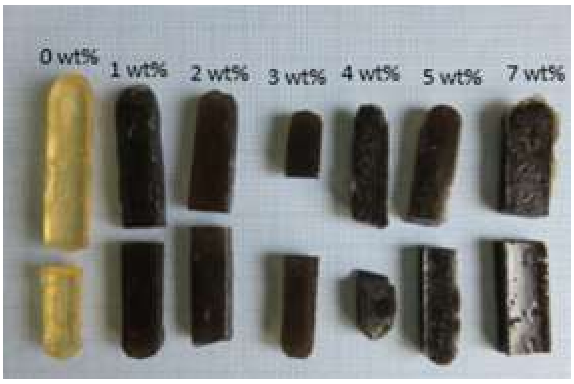

Figure 11: Samples of impact failed specimens of the SSA/polyester composites.

IV SSA Effects of on hardness characteristics

The hardness results for the SSA/polyester composites are presented in Figure 12. The hardness values were enhanced with addition of SSA to polyester matrix. The hardness slightly increased to 81.3 at 5 wt% of SSA particle loadings with improvement of 7% compared to unfilled polyester 76.2 then decreased. Figure 13 shows the samples of hardness shore D test of the SSA/polyester composites.

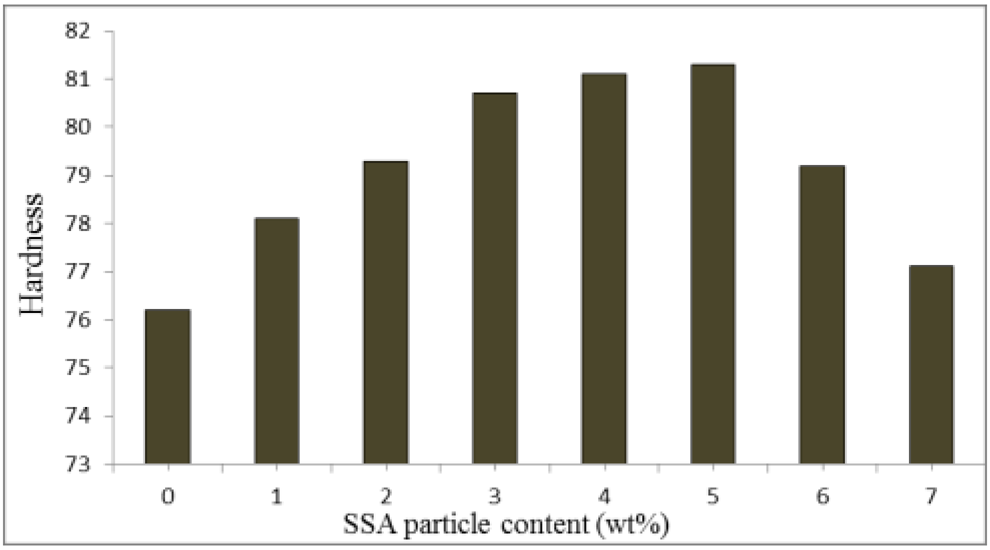

Figure 12: Hardness shore D for the SSA/polyester composites.

Figure 13: Samples of hardness of the SSA/polyester composites.

4. Conclusions

In this study, sewage sludge ash filler is added into polyester matrix composites. The tensile, flexural, Charpy impact and hardness tests were achieved on the samples SSA/polyester composite to obtain the mechanical properties of SSA-particle/polyester composites. However, it can be concluded that:

- The best improvement of tensile, flexural and Charpy impact strength were 232%, 167% and 153% at SSA particle loading of 5, 3, 5 wt%, respectively, and then steadily reduced. The hardness improved by 7% .
- The failure strain of tensile and flexural curves was decreased with more particles loading.
- The modulus of tensile and flexural curves increased up to a SSA loading of 3, and 6 wt%, respectively.
- The values of the mechanical characteristics of SSA-particle/polyester composites confirmed that after the particle loading of 5wt% the particles aggregation occurred .
- The benefits of that using of SSA can protect the environment due to increasing the amount of SSA can affect the environment badly and producing cheaper polymer composite for industrial applications.

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