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Microstructural and Mineralogical Analysis of Weak Erodible Soil for Gully Site Study and Solutions

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Abstract

The microstructure and mineralogy pattern of the two major erosion sites in Abia State has been studied using the X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) methods to examine the morphology and minerals abundant in the watershed. This is due to the danger the people of these areas are faced with regarding the rate and magnitude of gully development in that area. The results have shown that the flacked and flattened microstructure of the studied eroded soil contribute majorly to the rate of dispersion due to plastic deformation. Secondly, the minerals composition is such to increase the acidity of the soil in the studied region, which contributes to swelling action. Again, the traces of sodium in the morphological and mineralogical composition contribute also to swelling and this is due to rain pressure during rain and runoff. It is suggested that the soils surface of the erosion sites be treated and stabilized to improve on its strengthening abilities.

1. Introduction

Soils are eroded from watersheds causing gully erosion menace across the world [1, 2]. World environmental disaster management has marked the South-Eastern Nigeria as worst hit by gully formations across its landmass [3, 4]. Abia State for example has been hit by erosion hazards in most of its local councils like Ikwuano, Umuahia North, Isikwuato, etc. [1]. Due to the effects of climate change, the probability of extreme weather occurrence has increased in the last few decades [5]. In the West African regions, high intensity and long duration rainfall events leads to enormous magnitudes of sediment material to be carried down slope to the various watershed and downstream inducing emergency and disaster events [6]. These events coupled with improper termination of drainages has led to massive gully erosion synonymous with South Eastern Nigeria soil [1]. This menace gave rise to the study of two selected erosion sites namely Ikwuano and Umuagu gully erosion sites with the aim of running some tests on the samples taken from these sites and cross matching the result characteristics with international acceptable standards that explains soil strength and dispersivity [4]. During rain events, soils are subjected to water percolation and drop pressure that cause the interconnected particles to dislodge. Further action of this event causes a displacement of the dislodged particles and collection of the displaced or eroded soil at the downstream of the watershed. The dislodgment and displacement frequency depend primarily on the structural pattern, the elemental and oxides composition and mineralogical constituents of the soil within the watershed. According to Rowe *et al.* [5], there is no one definitive test to determine the dispersivity of a soil. The ones that are available carry some uncertainty and need to be compared against one another. Even so, clayey soils may be mixed up during the process of classification. Scanning electron microscopy (SEM) images are able to look at soil surfaces on microscopic levels and note distinct particle associations and interactive behavior.

2. Methodology

2.1 Study sites and sampling

Samples were collected from two major and deadly erosion sites in Abia State i.e.; Ikwuano: Amaegbu Erosion Site in Ugwuegbu Autonomous Community, Ikwuano Local Government Area geographically located on N 005° 21' 33.7" E 007° 38' 09.8" and on elevation of 101 meters above sea level and Umuagu: Umuagu Isingwu Gully Erosion Site in Amafor Community, Umuahia North Local Government Area geographically located on N 005° 32' 17.72" E 007° 28' 57.35" and on an elevation of 96 meters above sea level both in Abia State, Nigeria. These two erosion sites have placed Abia State on an environmentally unsafe factor index of the World Bank and have attracted international community attention in terms of environmental safety of lives and property in Africa.

2.2 Experimental Program

Preliminary tests for characterization and classification of the studied soils were carried out and among these were; particle size analysis, Atterberg limits, and specific gravity. These were carried out in accordance with British Standard requirements [7]. Further, the microstructural and mineralogical examinations were carried, which include the Scanning Electron Microscopy (SEM) test, X-ray Fluorescent (XRF) test and X-ray Diffraction (XRD) test.

2.2.1 Scanning electron microscopy (SEM)

The SEM test helped to determine soil microstructural pattern of the eroded samples collected from the studied erosion sites. This was conducted with SEM, FEI Nova Nano SEM 400, Holland. A scanning electron microscope (SEM) is used to generate surface images of a specimen on the microscopic level. It does this by scanning a specimen with a beam of high energy electrons in an optical column with different magnifications and wavelengths. The electrons emitted by the beam then interact with the atomic structure of the specimen and generate topographic images. Different types of electrons are produced from the beam, secondary and backscattered. If the microscope is also equipped with X-ray capabilities, the equipment can generate information about the elemental make-up of the structure as well as the specific location of those elements. The section serves to further discuss the processes occurring in the SEM optical column, the images produced by secondary and back-scattered electrons. The energy exposure of this study was done with 500x, 1000x and 1500x magnifications with beam wavelengths of 100µm, 80µm and 50µm respectively on the two eroded samples from the studied gully erosion sites.

2.2.2 X-ray fluorescence (XRF) test

This test enables the measurement of up to 83 elements of the periodic table in samples of various forms and nature: solids or liquids, conductive or non-conductive. The elemental and oxides compositions of the studied specimens were determined by this examination. This enabled a technical understanding of the reactive response of the erosion surface to erodibility factors.

2.2.3 X-Ray diffraction (XRD) test

XRD was conducted with D/Max-2500, Germany. It is primarily used for mineralogical composition determination thus;

- Identification of crystalline material (used for regulatory purposes or during development)
- Identification of different polymorphic forms
- Distinguishing between amorphous and crystalline material

Quantification of the percent crystallinity of a sample and for stability studies. The prominent question one may want to ask is why using XRD analysis? Knowledge about crystallinity is highly relevant, as a crystalline form is usually preferred in development. In contrast to amorphous material, a crystal has well-defined properties (melting point, solubility and IDR) – parameters that should be known in order to monitor and control the behavior of the soil.

3. Results and Discussion

3.1 Preliminary Characterization

The preliminary behavior of the soils has been tabulated in Table 1. The study has shown the microstructural pattern and features of the soil samples collected on the surface of gully head from both sites. According to ASSHTO classification, the sample from Ikwuano is an A-1-b type soil with stone fragments, gravel and sand. It has zero liquid limit, plastic limit and plasticity index. The grading characteristics and the geometrical properties of the soil, which are the uniformity coefficient (C_u), curvature coefficient (C_c) and the effective size (D_{10}) are 0 as presented in Fig. 1. The absence of any form of silt in this sample makes it lack the ability to bind; making it susceptible to erosion. Conversely, the Ikwuano eroded soil was classified as A-1-a according to AASHTO classification system. While the erosion site at Umuagu indicated the presence of little silt. It has plasticity index of zero, liquid limit of 2% and plastic limit of zero. The grading characteristics and the geometrical properties of the soil, which are the uniformity coefficient (C_u), curvature coefficient (C_c) and the effective size (D_{10}) are 3.28, 0.738 and 0.18 respectively. The amount of silt contained in this sample is so insignificant as shown in Fig. 2 that it can't contribute to any binding process as to hold the particles together beyond any dispersive or erosive agent like rain. Result from particle size distribution from both erosion sites shows that they are poorly graded. The samples from Umuagu and Ikwuano indicate silty sandy soils. Also, the various oxides found in the soil samples from Ikwuano gully erosion site were a total of 15 oxides with the highest being 83.55% Silicon Oxide (SiO_2) and 10.2% Al_2O_3 while the sample from Umuagu Gully erosion site has 69.70% Silicon Oxide (SiO_2), 9% Al_2O_3 and 15.5% Fe_2O_3 as presented in Tables 2 & 3. According to Smith and Callahan (1987), Fe oxides and oxy-hydroxides are not considered as possible cohesive or coagulating agents of soil particles, though they play a significant role in cementing some soils, although Fe and Al oxides and oxy-hydroxides contribute to soil particles and structural units bonding and to the formation of more compacted soil horizons. Knowledge of the interactions between clay silicates and iron and aluminum oxides is important for understanding the physical and chemical properties of soils, particularly the highly weathered soils of which they are the major compounds [8]. The soils spectral conditions are presented in Figs. 3 & 4 which present the sodium and chloride intensity and composition in the studied eroded soils of Umuagu and Ikwuano respectively. It can be shown that the Ikwuano eroded sample has higher sodium (Na) at very low energy exposure of about 2keV compare the Umuagu eroded sample which shows high sodium intensity at a high energy exposure of 7keV. Sodium (Na) is responsible for the swelling and unstable behavior of engineering soils, which yields to effects of erosive factors.

Table 1 preliminary property of studied eroded soils

Property description of soils and units	Values / Descriptions	
	Umuagu Eroded Soil	Ikwuano Eroded Soil
% Passing Sieve No 200	14	23
NMC (%)	7	6
LL (%)	2	0
PL (%)	0	0
PI (%)	2	0
SL (%)	0	0
FSI (%)	0	0
G_s	2.26	2.39
AASHTO Classification	A-1-a	A-1-b
USCS	GP	GP
MDD (g/cm^3)	2.45	2.80
OMC (%)	8.2	7.3
Color	Ash	Reddish Ash

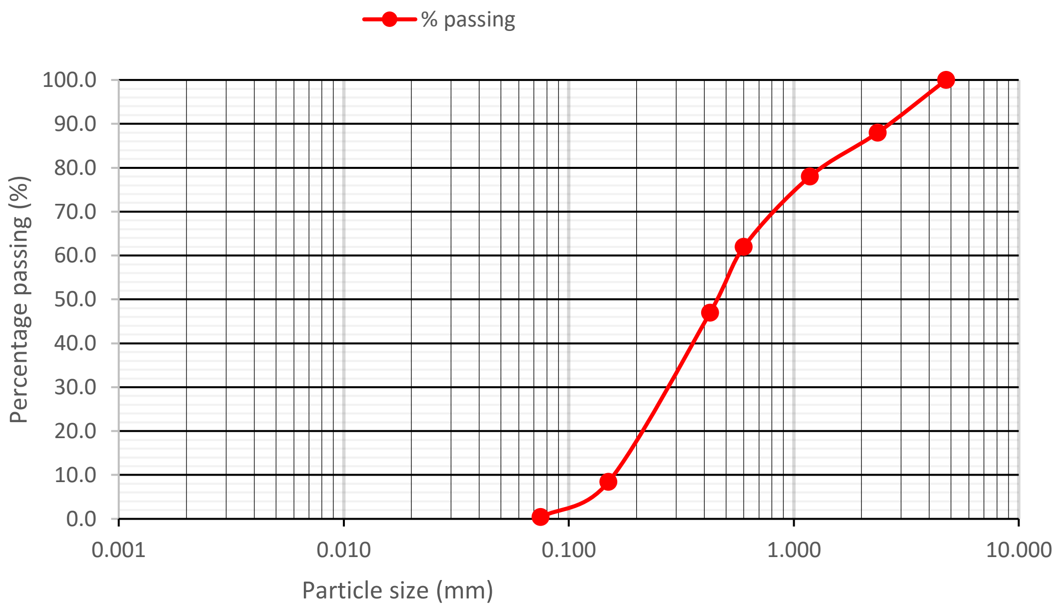

Fig. 1 Particle size distribution of Umuagu studied eroded soil

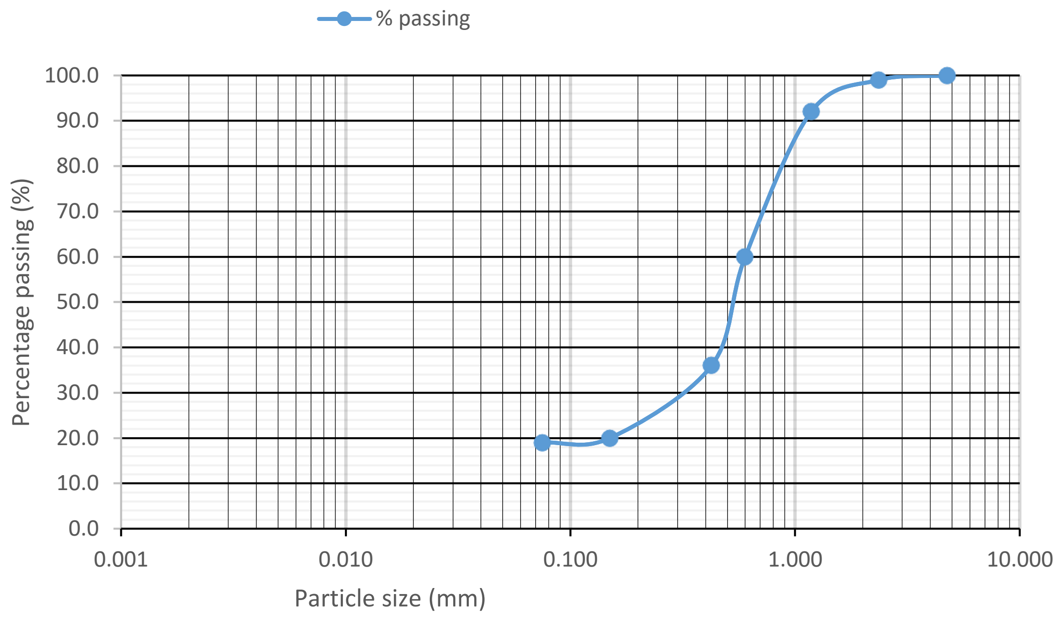

Fig. 2 Particle size distribution of Ikwuano studied eroded soil

Table 2 Elemental Composition of the erosion sites test soils

Soil Materials	Elemental Composition (content wt.conc. %)												
	Si	Al	Zr	Ti	Fe	Na	Mg	Cu	I	Ca	Cr	K	S	P
UmuaguSoil	63.70	20.66	0.70	1.07	9.23	1.23	1.02	-	-	0.78	-	-	1.04	0.57
Ikwuano Soil	73.19	9.38	3.74	3.57	2.87	1.47	1.12	1.01	1.00	0.99	0.94	0.73	-	-

Table 3 Chemical Oxides Compounds Composition of the erosion sites test soils

Soil Materials	Elemental Oxides Composition (content wt.conc. %)													
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	Mn_2O_3	Fe_2O_3	ZnO	SrO
Umuagu Soil	0.00	0.00	9.223	69.7	0.16	0.41	0.05	0.17	1.08	3.56	0.03	0.058	15.51	0.03	0.03
Ikwuano Soil	0.00	0.26	10.22	83.6	0.48	0.59	0.04	0.11	0.48	1.83	0.01	0.02	2.42	0.0	0.01

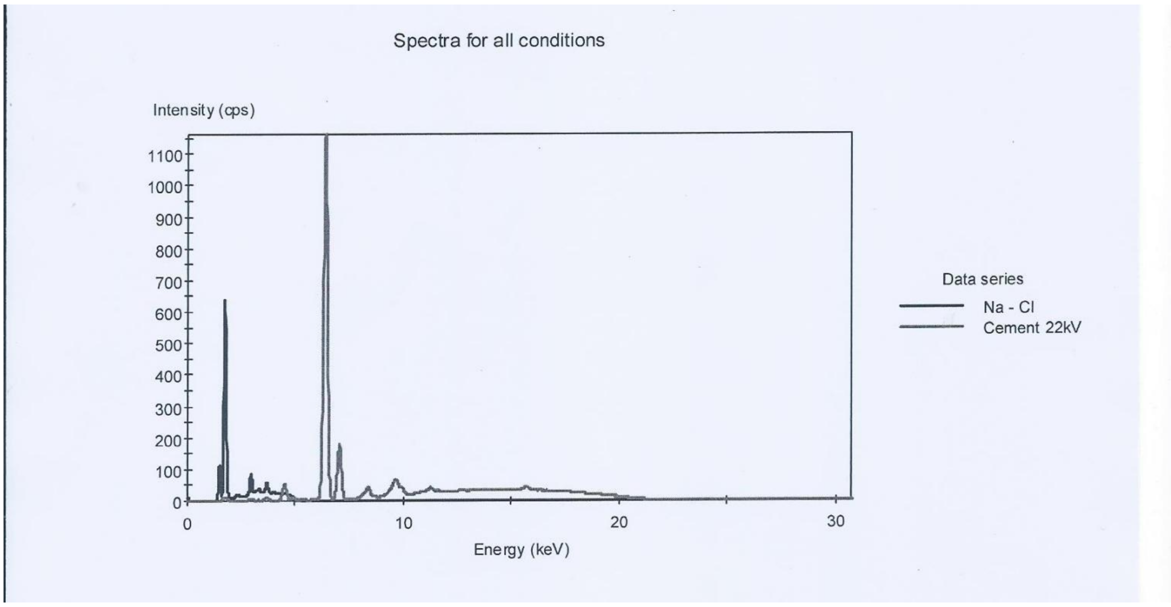

Fig. 3 Spectral conditions of Umuagu Erosion Site Eroded Soil

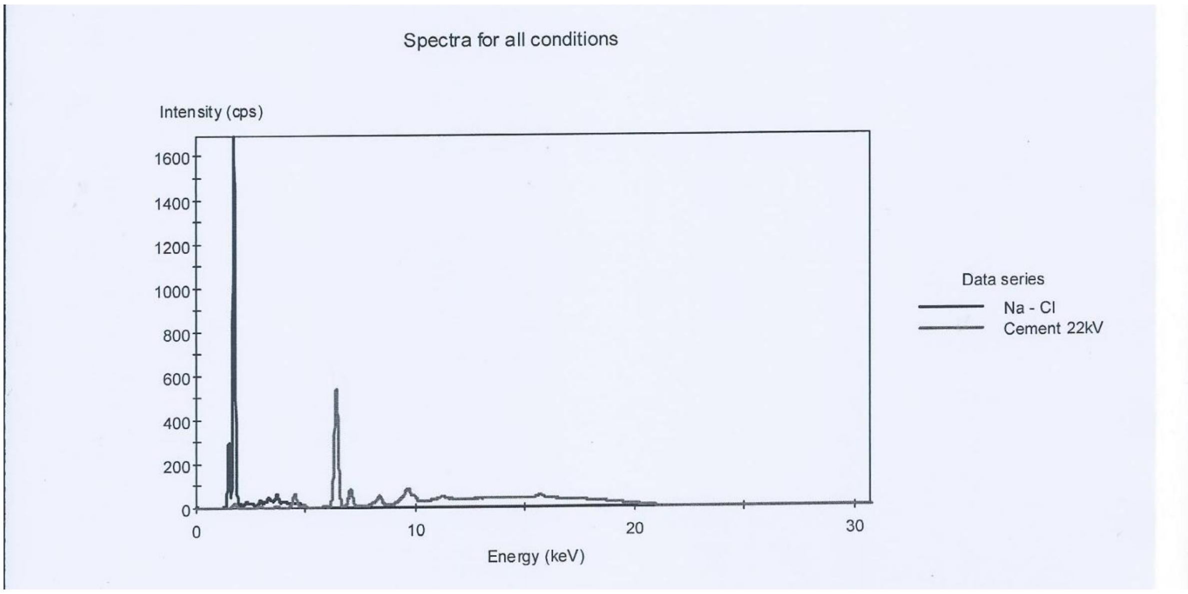

Fig. 4 Spectral conditions of Ikwuano Erosion Site Eroded Soil

3.2 Microstructure of the erosion sites eroded soils

Figs. 5, 6, & 7 and Figs. 8, 9 & 10 are the SEM images and morphology patterns of the studied Umuagu and Ikwuano eroded soil samples, which were exposed at the wavelength of 100, 80 and 50µm and magnification of 500x, 1000x and 1500x respectively. This shows the internal microstrains, phase constituents and microstructure of the studied specimen. This was exposed under room temperature and under laboratory conditions with a dispersion energy of 15kV. The soil under discussion has been characterized as zero plastic soil, hence lack the cementation with less agglomeration of discrete particles which can be observed to be spheroidal in shape with irregular structure. This structure as observed shows that internal fracture takes place due to plastic deformation of the mass when exposed to dispersive energy like the rain. This tries to dislodge the weak bonds existing within the soil mass, disperse same and displace the dislodged particles as the pressure increases. The period of rain is usually supersaturated in a state of solid-liquid state intra-diffusion, which equally induces chemical reactions between soil elements and oxides and the percolated water as it migrates through the fractured pores and internal lines of the soil structure. This further also brings about amorphization and deagglomeration of the internal structure of the soil and eventually yields the contact force or intergranular force between the elements. The particles are equally observed to be flattened and flakes to form irregular structure, which are fragile on severe plastic deformations when rain pressured particles collide with the soil mass as well as run off impacts leading to increased micorstrains and decrease contact energy between particles. Hence, they fracture, deagglomerate and disperse on prolonged exposure [2, 8]. The studied region or watershed is subjected to multidimensional effects of rain and runoff exposing the watershed to erosion determinant factors. And these aren’t friendly to the environment. However, the structure of the studied soil in the exposed region contribute to failure of the environment and propagation gully sites within and without the south eastern region of Nigeria. Due to lack of cementation, grain or discrete particle boundaries are formed within the microstructure of the studied region as can be seen from the SEM morphology and exposures, which induces supersaturated solid-liquid conditions in the mass of the soil structure. This also results in lattice distortion and crystallization and eventually dispersion of soil particles [2, 8].

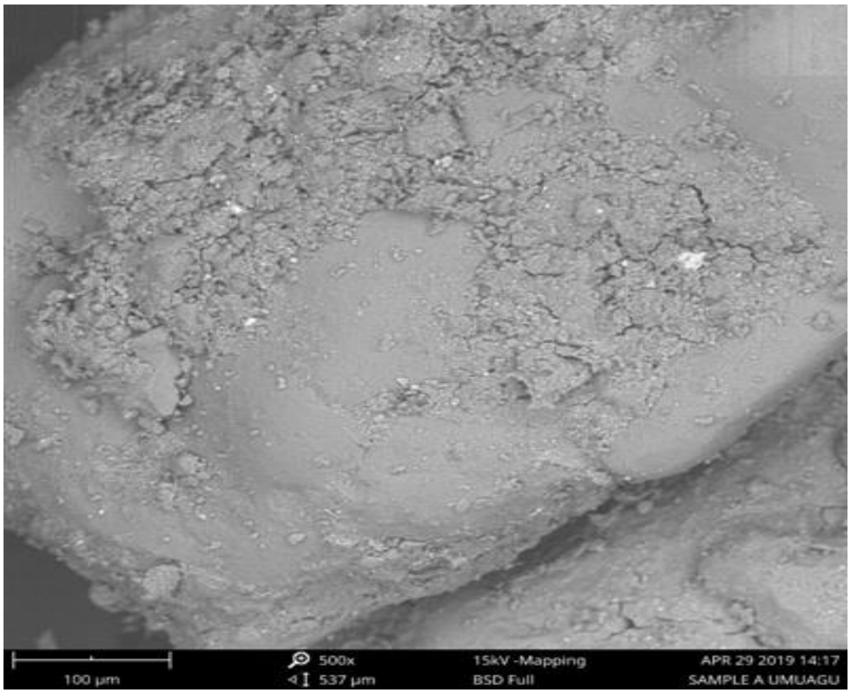

Fig. 5 Scanning Electron Microscopy (SEM) morphology of Umuagu eroded Soil 100µm and 500x exposure

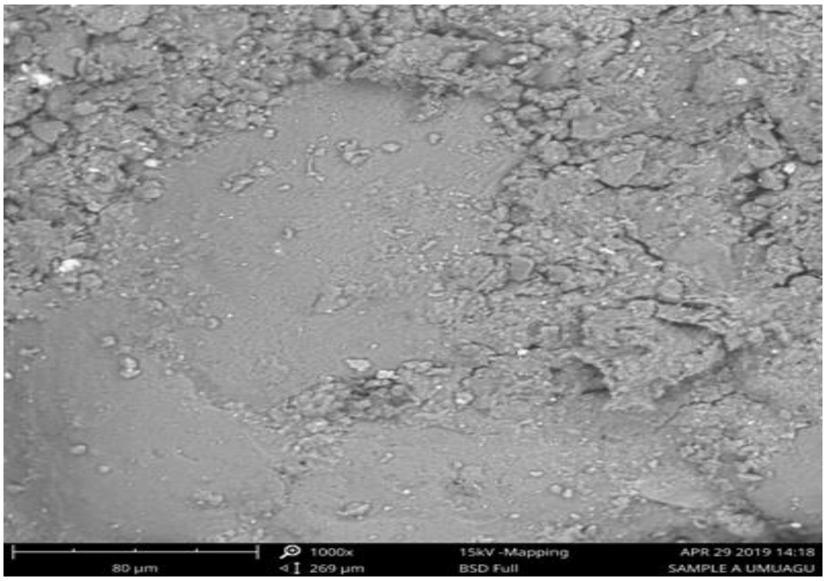

Fig. 6 Scanning Electron Microscopy (SEM) morphology of Umuagu eroded Soil 80µm and 1000x exposure

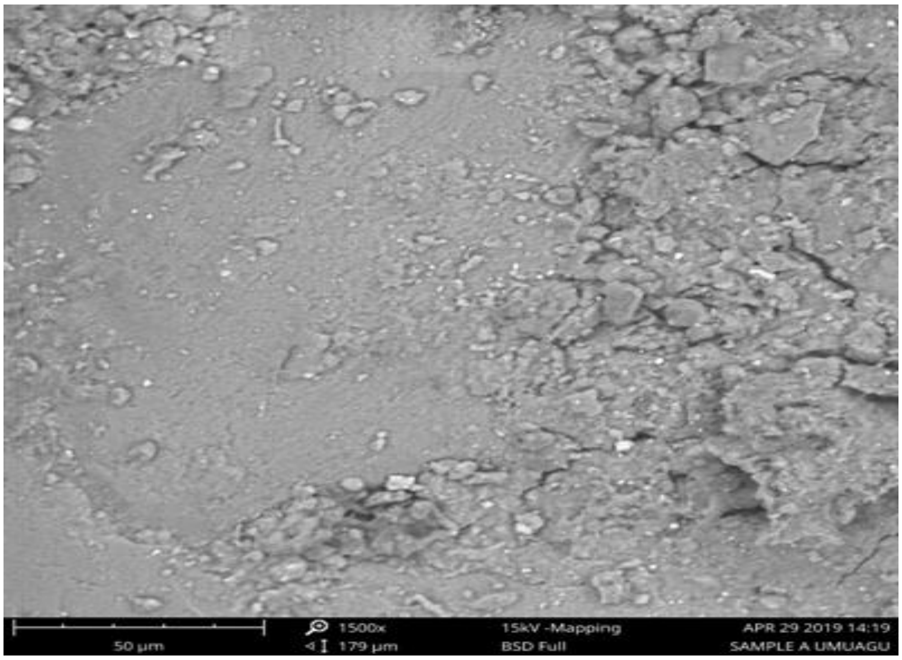

Fig. 7 Scanning Electron Microscopy (SEM) morphology of Umuagu eroded Soil 50µm and 1500x exposure

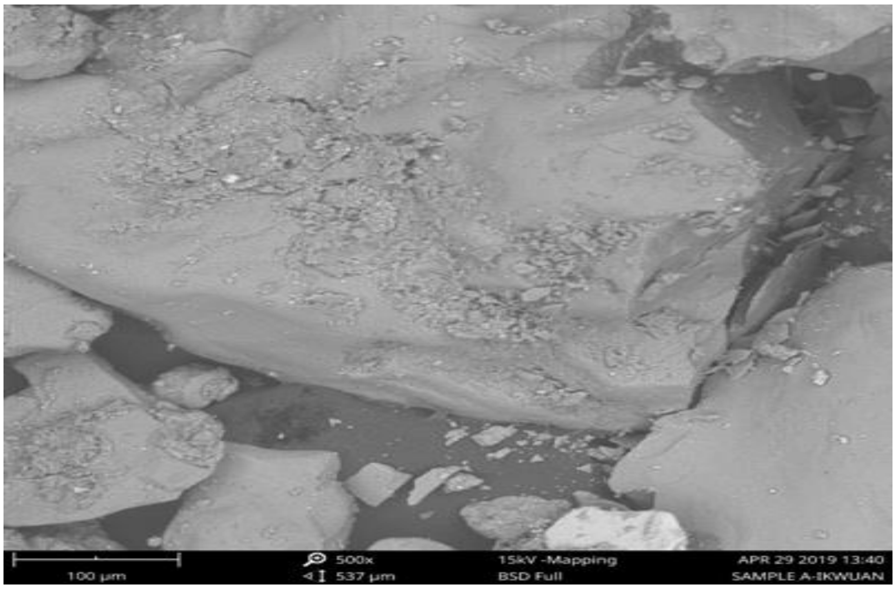

Fig. 8 Scanning Electron Microscopy (SEM) morphology of Ikwuano eroded soil 100µm and 500x exposure

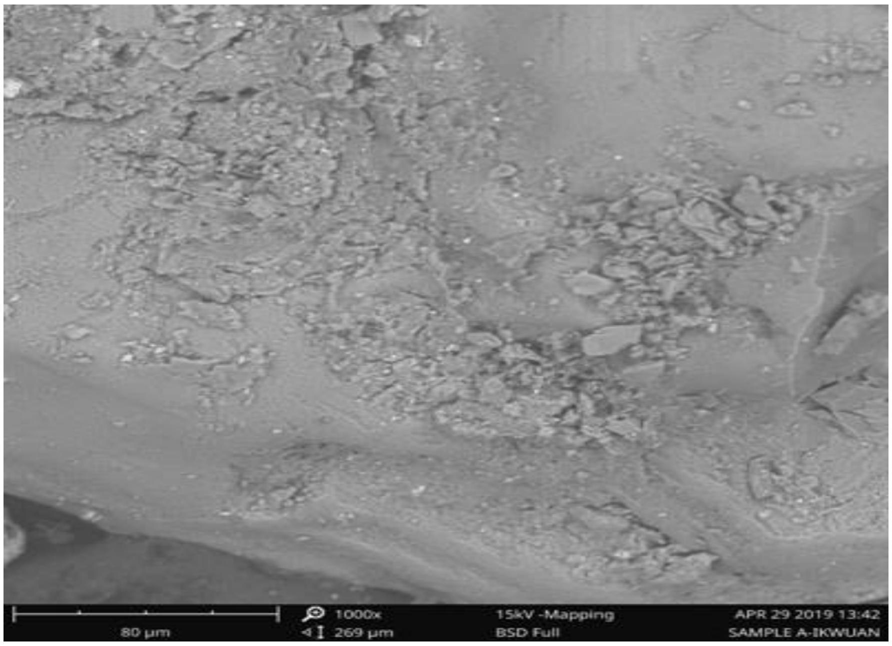

Fig. 9 Scanning Electron Microscopy (SEM) morphology of Ikwuano eroded soil 80µm and 1000x exposure

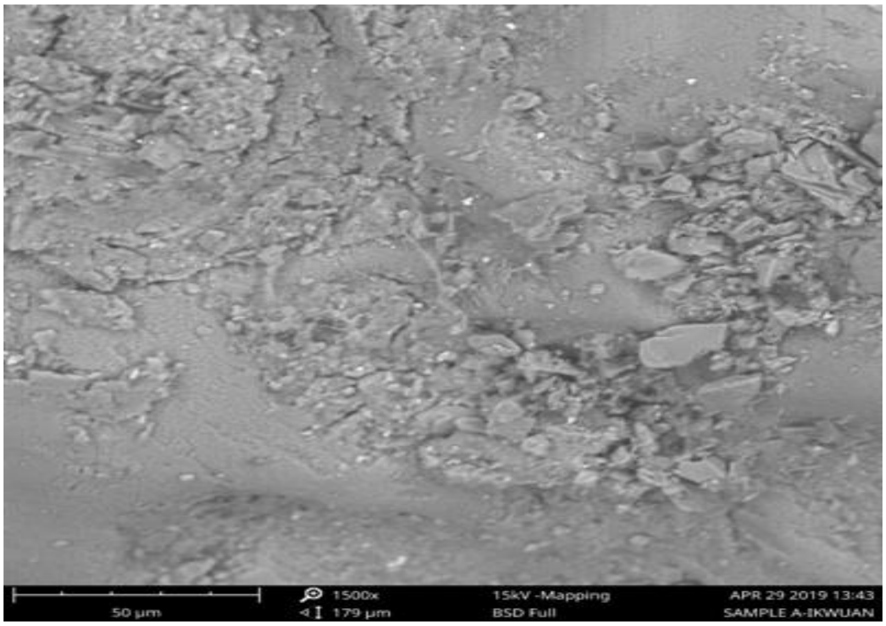

Fig. 10 Scanning Electron Microscopy (SEM) morphology of Ikwuano eroded soil 50µm and 1500x exposure

3.3 Mineralogical and Oxide Composition Concentration of the Erosion Sites Eroded Soils

Figs. 11 & 12 present the elemental and mineralogical configuration of the Umuagu studied eroded soil while Figs. 13 & 14 present that of Ikwuano studied eroded soil. In these examinations, this work tries to assess and evaluate the contribution from the elemental composition and mineralogical pattern of the soils from two studied regions to the menace of erosion and gully development in the regions. However, this will help establish possible ways to deal with this environmental problem. From Figs. 11 & 12, it can be deduced that the dominating elements are silicon and aluminum and the domination mineral is quartz. Fig. 11 also shows strong traces of sodium, an element responsible for weakening and swelling in soils. Conversely, the dominating elements and minerals recorded for Ikwuano test soil in Figs. 13 & 14 are silicon, iodine and aluminum and also quartz. It also has strong traces of sodium. Quartz is one-part silicon and two parts oxygen, which is also called silica. And this mineral compound causes high acidity in soils by lowering the pH scale [2, 8]. And soil acidity affects the structure of soils and increases its tendency to react with water during rain or runoff. Kaolinite on the other hand is the clay mineral that dominates in the structure of the two studied soils. The soils swell under the influence of sodium on prolonged exposure to water. The studied Ikwuano soil has shown to possess weak deformation peaks due to plastic deformations induced by the presence of sodium [2, 8, 9]. The microstructural minerals and elements in the clayey soils are responsible for the reactions that lead to flocculation, strengthening and geopolymerization. It is evident that the traces sodium contained in studied eroded soils contribute to the rate and magnitude at which dispersion and displacement of particles occur at the surface of the erosion watershed. Hence, the gully development in the studied region.

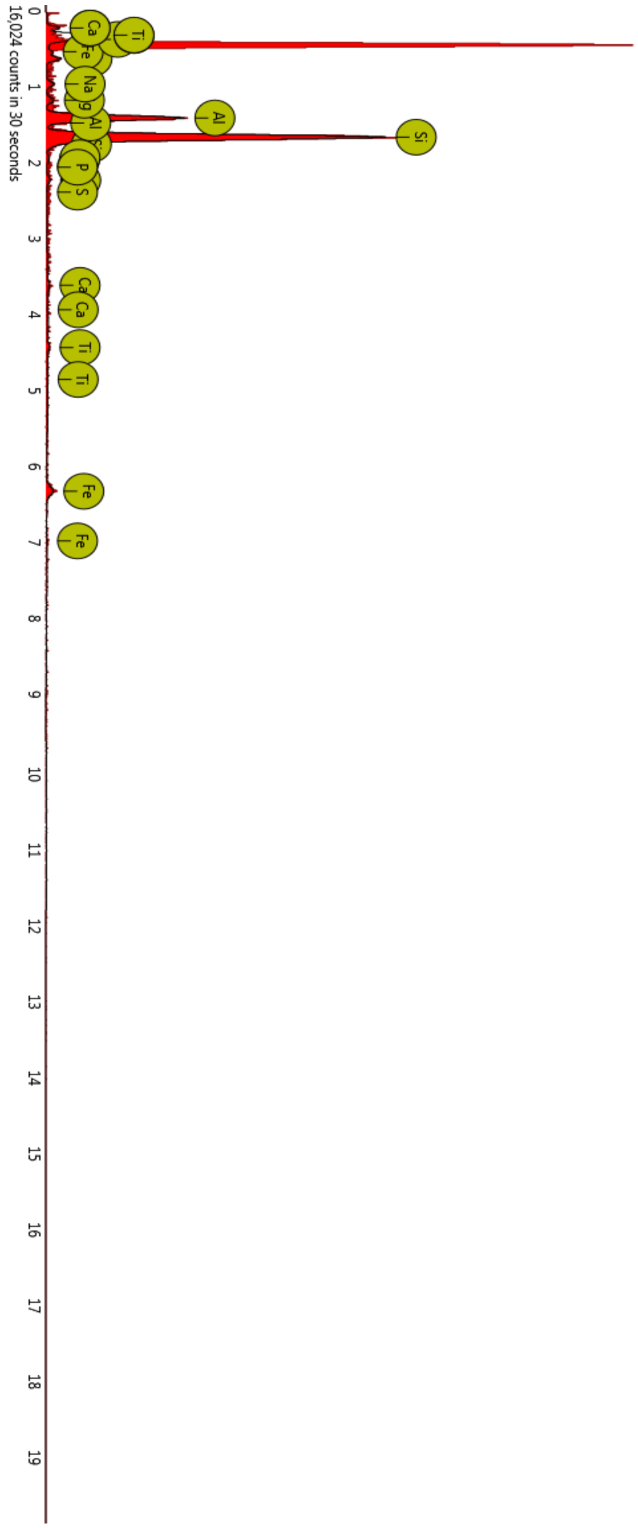

Fig. 11 Elemental diffractograph of Umuagu Erosion Site Eroded Soil

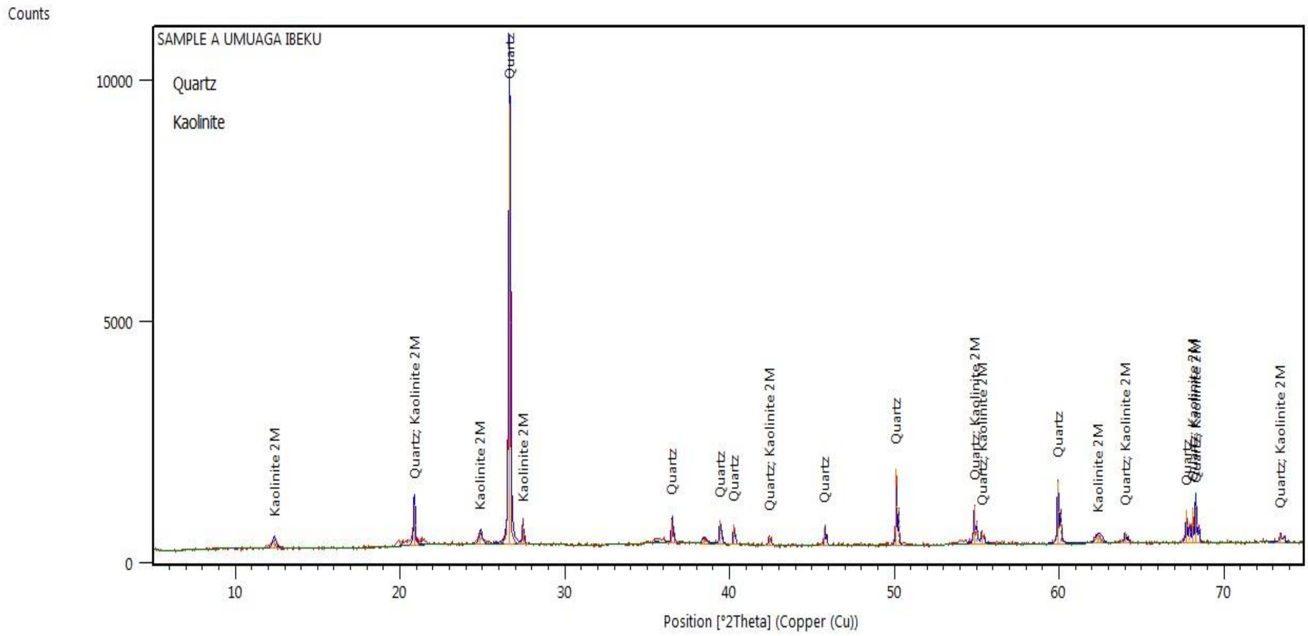

Fig. 12 Mineralogical X-Ray Diffractograph of Umuagu Erosion Site Eroded Soil

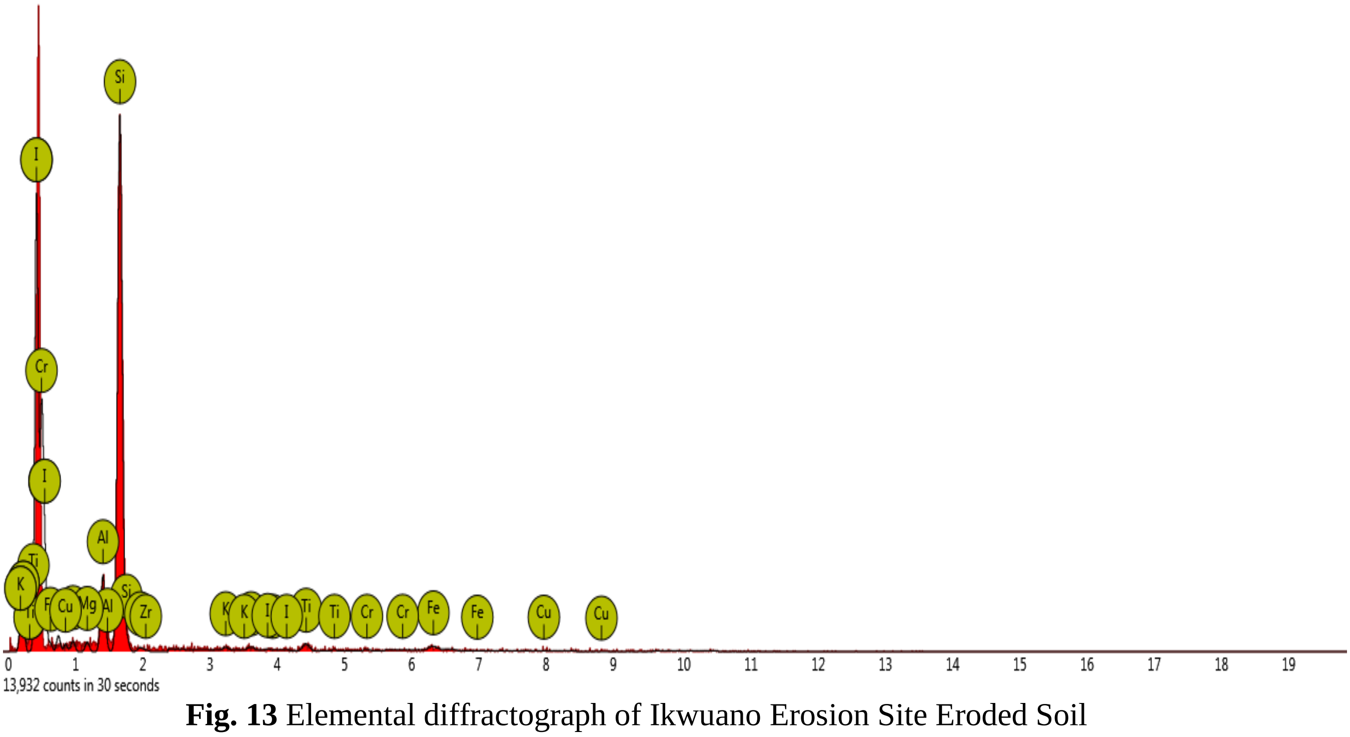

Fig. 13 Elemental diffractograph of Ikwuano Erosion Site Eroded Soil

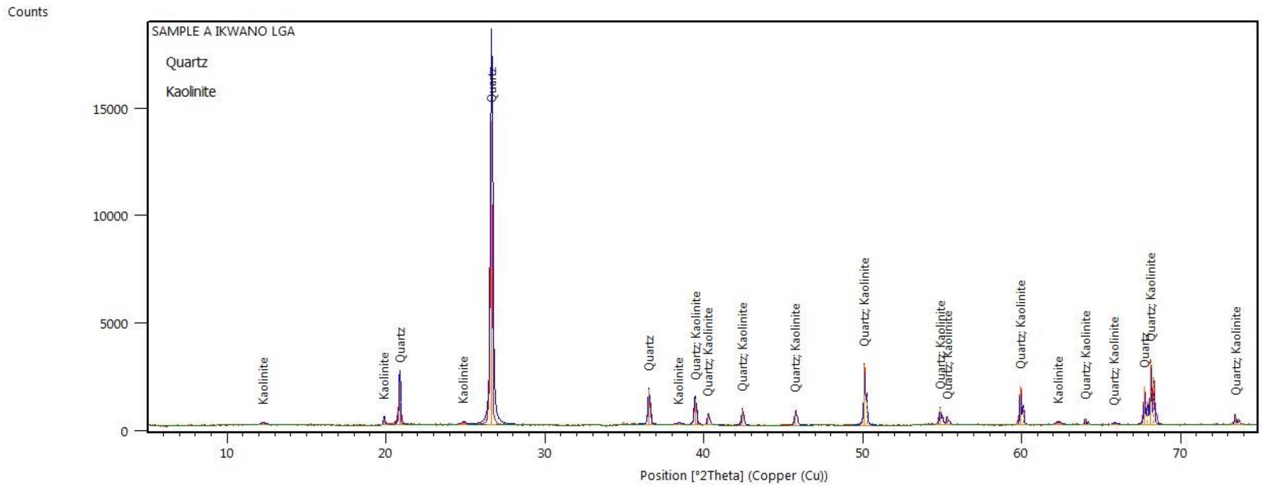

Fig. 14 Mineralogical X-Ray Diffractograph of Umuagu Erosion Site Eroded Soil

4. Conclusion

The research work on the microstructural and mineralogical evaluation of the erosion sites in Umuagu and Ikwuano, Nigeria has shown remarkable results on how best to respond to the menace on the microstructural level and as well the macrostructural level. The results have shown that the clear evidence behind the magnitude of soil washing on the erosion sites is the presence of sodium and high peak of acidity within the studied region. This worsens the rate of gully development in an exponential degree. The silicon and of course silica (quartz) level is commendable but that is not enough to resist dispersion effects. The anhydrous minerals of quartz and kaolinite are detected at the peak of the diffractograph of the XRD pattern and plays a role during hydration. The supersaturation of which yields to the determinants of erosion. These cause the soil structure to yield and particles dislodge. Generally, the studied watershed is strongly recommended to be treated with eco-friendly supplementary cementing materials and stabilized to reduce to the barest minimum or even to zero the magnitude of soils dispersions, dislodgment and displacement happening in the studied area, which gives rise to gully development and its attendant environmental hazard. This process will harness the abundant silica to enhance hydration, cation exchange, calcination, carbonation and geopolymerization in the promotion of flocculation and strengthening in the soil structure.

Conflict of Interest

The authors declare no conflict of interests in this work

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Nomenclature

AASHTO	American Association of State Highway Officials
SEM	Scanning Electron Microscope
XRD	X-ray Diffractometer

XRF	X-ray Fluorescent
Cc	Coefficient of curvature
Cu	Coefficient of uniformity
D_{10}	Effective size
NMC	Natural moisture content
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
SL	Shrinkage limit
FSI	Free swell index
Gs	Specific gravity
UCS	Unconfined compressive strength
USCS	Universal soil classification index
MDD	Maximum dry density
OMC	Optimum moisture content
Si/SiO_2	Silicon/Silica
Al/Al_2O_3	Aluminum/Alumina
Na/Na_2O	Sodium/Sodium Oxide
Mg/MgO	Magnesium/Magnesium Oxide
Fe/ Fe_2O_3	Iron/Iron Oxide
Ca/Cao	Calcium/Calcium Oxide
Ti/ TiO_2	Titanium/Titanium Oxide
μm	Micrometer

References

[1] Onyelowe, K. C. (2017). The menace of the Geo-Environmental hazard caused by gully erosion in Abia State, Nigeria. Environmental Technology & Innovation 8; 343–348. www.elsevier.com/locate/eti. http://dx.doi.org/10.1016/j.eti.2017.08.006.

[2] M. H. Abdelaziz, A. M. Samuel, H. W. Doty, S. Valtierra, F. H. Samuel (2019). Effect of additives on the microstructure and tensile properties of Al–Si alloys. Journal of Materials Research and Technology, Vol. 8(2), pp. 2455-2468. https://doi.org/10.1016/j.jmrt.2019.03.003

[3] Onyelowe, K. C., Bui Van, D., Ikpemo, O. C., Ubachukwu O. A., & Van Nguyen, M. (2018). Assessment of rainstorm induced sediment deposition, gully development at Ikot Ekpene, Nigeria and the devastating effect on the environment. Environmental Technology and Innovations, Vol. 10, Pp. 194-207. https://doi.org/10.1016/j.eti.2018.02.008.

[4] Onyelowe, K. C. & Maduabuchi, M. N. (2017). Gully Erosion at Amuzukwu-Ibeku, Umuahia, Abia State; a review. *Proceedings of the 18th International Conference and 38th AGM of the Nigerian Institute of Agricultural Engineers (NIAE), Umudike*, 3rd to 5th of October, 2017. Pp. 483-485.

[5] Rowe, D., Greene, G., Warner, S. & Gimre, K., (2017). Remediation and water resource protection under changing climatic conditions. Environmental Technology & Technology, Vol. 8, pp. 291-298. https://doi.org/10.1016/j.eti.2017.07.008

[6] Y. Xua, Y. Suna, X. Daia, B. Liaoa, S. Zhoua, & D. Chen (2019). Microstructure and magnetic properties of amorphous/nanocrystalline Ti50Fe50 alloys prepared by mechanical alloying. Journal of Materials Research and Technology, Vol. 8(3), pp. 2486-2493. https://doi.org/10.1016/j.jmrt.2019.02.007

[7] BS1377-2, 3, (1990). Methods of Testing Soils for Civil Engineering Purposes, British Standard Institute, London.

[8] Manuel, A., M. Teresa B. & F-Nosco D. (1995). Effects of Iron and Aluminium Oxides on The Colloidal and Surface Properties of Kaolin. Clays and Clay Minerals. Vol. 43 (4); 406-416.

[9] Smith, B. R., & Callahan, L. L. (1987). Soils with Bx horizons in the upper Coastal Plains of South Carolina. Soil Science Society of America Journal 51: 158-164.