Use of Modified Palm Kernel Shell Particles Composite Blend with Cement or Clay as Alternative Material for Block Production

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Abstract

This study presents the potential of modified Palm Kernel Shell (MPKS) particles in the production of blocks as an alternative building material using cement or clay as binders. Several studies on Palm Kernel Shell (PKS) as a blend with other natural fibres/fillers found that due to its hydrophilic nature, it has low physical and mechanical capabilities in comparison to MPKS, making it less compatible with any polymeric matrix. Experimental tests were conducted to determine the physicomechanical attributes of MPKS/Cement and MPKS/Clay blocks, including characterization of the cement and clay using Atomic Absorption Spectroscopy (AAS), as well as moisture content, water absorption, hardness, apparent porosity, bulk density, compressive strength, and flake. The morphology of the samples was determined using Scanning Electron Microscope (SEM). Results show that MPKS/Cement block samples exhibit superior physicomechanical and morphological properties compared to MPKS/Clay. The MPKS/Cement block sample moisture content ranged between 4.76 – 9.94%. The 80/20 MPKS/Cement sample recorded the most water absorption at 49.5%, and a microhardness value of 82.3 Hv for the 20/80 sample. The MPKS/Clay samples showed higher values of apparent porosity but recorded the least bulk density in the 80/20 samples. The 20/80 MPKS/Cement and MPKS/Clay samples showed the best compressive strength at 63.72 and 50.3 N/mm^2 respectively, while 80/20 for both cement and clay displayed very weak compressive strengths. The ratio 20/80 of MPKS/Cement is observed to be the optimum ratio where better properties of the composites were obtained. For the structure industry's long-term viability, MPKS' superior mechanical properties as an aggregate in block manufacturing make it an asset material as an alternative for some high-cost construction resources such as sand.

1.0 Introduction

One of the reasons for building collapse in Nigeria has been attributed to the use of sub-standard building materials [1], many of which are imported, expensive, and not suited for the local environment. As a result, there is a deliberate government policy drive towards the utilization of locally sourced alternative materials [2, 3] which could be better adapted to the environmental conditions in the country and, would make housing affordable to low-income earners [4, 5]. Some of the locally sourced materials are natural fibres employed as reinforcers or aggregate components in replacement of some expensive materials such as sand in block production, with clay or cement manufactured by indigenous companies. Idder et al., [6] analyzed the physical behaviour of Stabilized Earth Block reinforced with Date Palm fibre. Their study was to develop blocks with optimum physical properties which would contribute to reducing the price of housing. Other examples of fibres used in construction include coir, palm kernel shell, sisal [7], eucalyptus grandis pulp, Malva, ramie bast, jute, pineapple leaf, kenaf bast, abaca leaf, bamboo, banana, hemp, flax, and sugarcane fibres, etc [8, 9]. Natural fibres due to their abundance and easy access bring down the cost of construction, enhance the tensile and compressive strength of the construction material, lightweight and corrosion-resistant [8]. Regardless of these recorded benefits, they also come with some drawbacks as they are susceptible to alkali attack by the pore water present in the cement matrix [10]. Ichetaonye et al.[11] investigated the use of Palm Kernel Shell (PKS) and Balanite shell for sustainable alternative ceiling boards. They suggested that the negative effects of natural fibre as a filler could be mitigated by altering the filler-matrix interface interactions with chemical treatments. To maximize the cement hydration process, they also suggested that reinforced particles be treated.

Palm kernel shells (PKS) have gained tremendous interest as filler material in block and mortar production [12, 13]. Palm oil production results in various waste materials such as palm kernel shells, empty fruit bunches, etc. In a few urban or rural groups, these agro–waste products are stockpiled in open landfills causing an environmental nuisance, air pollution, drainage blockages, etc [14–16]. Also, in some communities, palm kernel shell is often utilized in combustion processes with wood or sawdust to modify the biomass feed to the boiler [17]. Moreso, these aggregates are been deposited on untarred roads for vehicular traction [18, 19]. Umana [20] reported that only 70% of PKS from oil palm processing mills are utilized in Nigeria, with the majority used as solid fuels for steam boilers. Very little is used in construction.

Imman et. al., [21] resolved that palm kernel shell as a construction material can be utilized for affordable housing since they recorded 18 MPa compressive strength. With an appropriate mixture, it could be used for modification of concrete ranging from 20 to 30 MPa.

Cement is an inorganic substance or binder which consists of lime or calcium silicate, used for construction which adheres and hardens to other materials by binding them together e.g. sand and aggregate. It is the second most-consumed resource after water on the planet [22], which may be used for mortar for masonry or concrete. Also, it can be characterized as non-hydraulic or hydraulic, depending on the cement's ability to set in the presence of water [23]. Cement is a major component of concrete production. However other nano and pozzolanic materials like n-SiO_2, fly ash, and rice husk ash have been employed as alternative materials. Kate et al.[24] used the Taguchi technique and multi-regression analysis to study the optimization of sustainable high-strength-high-volume fly ash concrete with and without steel fibre. They determined that, based on the results of multi-regression and Taguchi experiments, cement is the most important control element for split tensile strength, and that it is also a more suitable sustainable material that has superior properties to regular concrete. The influence of SiO_2 and ZnO nano-composites on the mechanical and chemical properties of modified concrete was studied by Nayak et al. [25]. They found that adding n-SiO_2 additives with 0.75 percent substitution and n-ZnO additives with 0.5 percent replacement to cement improves compressive strength and split tensile strength. Furthermore, not all nano-materials are suitable for substituting cement to improve its durability and structural strength, thus it is critical to consider the nano-properties, material's structure, interaction, and texture with cement hydration.

Clay is a general term including many combinations of one or more clay minerals such as hydrous aluminum silicates with traces of metal oxides and organic matter, potassium, calcium, magnesium, iron, etc. Clay is a product of the decomposition of granite rock. Seventy-five percent of the earth’s crust is made of alumina/silica, two of the major constituents of clay. The alumina/silica are refractory (resistant to heat) and chemically inert. After long exposure to moisture, the alumina and silica become hydrated to produce clay mixed with water in certain proportions with the ability to bend and also flex.

The thrust of this research is to exploit MPKS as an alternative building material for low-cost buildings. Currently, there are several verifiable results of completed studies on PKS as an aggregate material or in combination with other natural fibres for block manufacture in literature. However, there are few studies on its modification for inclusion as aggregate in block production. Physico-mechanical and morphological properties of the developed samples of MPKS/cement blocks were compared to that of the MPKS/clay blocks.

2.0 Materials And Equipment

2.0.1 Materials

The materials utilized for this experimental study are Ordinary Portland Cement (OPC) manufactured by Dangote Cement, Nigeria, Natural clay obtained around Yaba College of Technology environment, south-west, Nigeria with GPS location 6.6172° N, 3.3200° E whose chemical compositions are shown in Table 1 and 2 respectively. Distilled water, PKS collected from Umuodum village, Isiala Mbano, Imo-State, Nigeria (latitude 5.708522^0 N and longitude 7.177533^0 E) was modified to MPKS. Acetic acid (PLR 0553 / 5008 ML 0553/01) and caustic soda (E. Merck 642771) were bought at a chemical shop at Mushin market, Lagos, Nigeria. 88 Universal mould release wax (Meguiar's Mirror Glaze) for easy removal of the formed block in the mould.

2.0.2 Equipment

The equipment used is; a Drier (oven) DK-9070A to extract any absorbed moisture on the aggregates or block samples. A Pocket Scale digital weighing balance; model: Black AWS – 100g, and Ohaus' Daul Spring Scale, model 8011-M were employed to determine the specific weight of the MPKS aggregates for mixture and block samples before and after each physical or mechanical test. SETHI Standard Test Sieve (BSS 36), a fabricated 2-piece cylindrical mould with detachable base and Laboratory Rammer were used for sieving the MPKS particles into specific sizes, casting the MPKS blocks in a cylindrical shape, and compacting the block samples respectively.

2.1 Methods

2.1.1 Chemical Treatment

The sieved PKS particles treatment was carried out by immersion into a NaOH solution with a concentration of 6% for 3 hrs at room temperature. After treatment, the PKS was washed with acetic acid, rinsed severally with distilled water, and finally sun-dried for 48 Hrs.

2.1.2 Block Preparation

Various cylindrical block samples of 38 mm x 12 mm were made by mixing the modified palm kernel shell (MPKS) particles as reinforcement filler with cement or clay as the binder in the ratios of 20/80, 40/60, 50/50, 60/40, and 80/20 and denoted as sample A, B, C, D, and E respectively (Fig. 2 and 3). These were left to sun dry for 28 days and then subjected to physicomechanical and morphological tests. Atomic Absorption Spectroscopy analysis of the OPC and clay samples are presented in Tables 1 and 2.

3.0 Tests

3.0.1 Atomic Absorption Spectrometry

The atomic absorption spectrometry (AAS) was determined by taking some samples of the OPC and clay for compositional analyses at Fetch Gate Laboratory (FGL), Gbagada, Lagos, Nigeria. The analyses were ascertained using energy dispersive X-ray Fluorescence Spectrometer model 9900 intel. A certain quantity of the cement was pressed in a hydraulic laboratory press which was immediately loaded into the sample chamber of the spectrometer. With a system current of 1 mA, at a voltage of 23 kV, and for 43 seconds, the loaded sample was excited. Thereafter, the system software was used for the analysis of the result. The same process was followed for that of the clay.

3.0.2 Moisture Content

Moisture content (MC) was determined by weighing each block sample (38mm x 12 mm) of both cement and clay at their various ratios (M_1). Thereafter, they were oven-dried at 150° C for 2 Hrs and then reweighed (M_2). The difference in mass was calculated using eq. (1).

$$\%MC = \left(\frac{M_2 - M_1}{M_1}\right) \times 100 \qquad (1)$$

Where M_1 = Weight before drying

M_2 = Weight after drying

3.0.3 Water Absorption

The water absorption (WA) was determined by immersing a dried 38 mm x 12 mm weighed specimen (W_d) in a 250 ml beaker of water for 3 Hrs. After which they were taken out, wiped with a clean cloth, weighed (W_w), and recorded according to BS EN1097-6:2000. The WA was calculated using eq. (2).

$$\%WA = \left(\frac{W_w - W_d}{W_d}\right) \times 100 \qquad (2)$$

Where W_d = Initial dried weight

W_w= Final weight

3.0.4 Microhardness

The microhardness (MH) was determined by placing a specimen in a Leitz Hardness (OS-2H) tester. This tester had a diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces under a load of 3 N following BS EN 12390-2:2009.

3.0.5 Apparent Porosity

Apparent porosity (AP) and Bulk density (BD) were determined by weighing a 38 mm x 12 mm dried block specimen (W_d) for cement and clay of each filler ratio. The specimens were soaked in water for 3 Hrs and the wet weight of the specimens was taken as (W_w). Finally, the specimens were weighed as (W_s) when suspended in water using the BS EN1097-6:2000. The AP was calculated using eq. (3) while the BD was determined with eq. (4), where ρw is the density of water.

$$\%AP = \left(\frac{W_w - W_d}{W_w - W_s}\right) \times 100 \qquad (3)$$

$$\%BD = \left(\frac{W_d * \rho w}{W_w - W_s}\right) \left| g/_{cm^3} \right| \qquad (4)$$

3.0.6 Compression Strength

The compressive strength (CS) of all the samples was determined using the computerized universal testing machine. All samples were placed between two compression discs and the pressure was applied until failure of the sample was obtained. The test method referred to the standard test of ASTM C67 and this was done under an ambient laboratory environment.

3.0.7 Flake Test

Flake test (F_t) was determined using the BS EN 933-3:1997 by weighing a dried specimen block 38 mm x 12 mm of each filler ratio of Cement and Clay (W_1). A hard shoe brush was used to make 20 strokes of forwarding and backward movements each against the two surfaces of the block[11]. The flaked board was then weighed (W_2). The F_t was calculated using eq. (5).

$$\mathrm{Ft} = \left(\frac{W_1 - W_2}{W_1} \right) \quad (5)$$

Where W_1 = Initial dried weight

W_2 = Final weight

3.0.8 Scanning Electron Microscope

The scanning electron microscope (SEM) was determined by placing a small piece of the dried compacted specimens in a PHENOM G2 Pro SEM machine to access the morphology of the specimen on the monitor screen using 15.0 kV.

4.0 Results And Discussion

Figure 1 (a) Dried PKS (b) Ground PKS (c) Ordinary Portland cement (OPC) (d) Clay powder (e) Cylindrical mould

Table 1: Atomic Absorption Spectroscopy analysis of OPC

Parameter	OPC (%)
SiO_2	23.0
Al_2O_3	3.22
Fe_2O_3	3.85
CaO	65.88
MgO	2.0
Na_2O	0.21
K_2O	0.30
SO_3	1.50

The results in Table 1 revealed that the Portland cement had Fe_2O_3, SiO_2, CaO, Al_2O_3, and MgO percentage contents of 3.85%, 23%, 65.88%, 3.22%, and 2% respectively. These percentage contents are within the acceptable standard for general-purpose cement following ASTM C 150 and BSI (1978). These are influential circumstances for predicting cement samples' effectiveness. Other mineral oxides such as

Na_2O, K_2O, and SO_2 with a percentage value of 0.21%, 0.31%, and 1.50% respectively are regarded harmless and may help in improving the cement properties since their values are below 1.75%. If not, essential elements of the cement may be displaced. [26–28] also had related results to compare with Nigeria cement.

Table 2: Atomic Absorption Spectroscopy analysis of clay sample

Parameter	Clay (%)
CaO	0.14
Fe_2O_3	0.03
MnO	0.000
TiO_2	0.01
Al_2O_3	39.51
MgO	0.06
L.O.I	0.06
P_2O_5	0.000
K_2O	1.33
SiO_2	51.31
H_2O	0.002
NaO_2	7.04

The composition analysis of the natural clay as determined by AAS is given in Table 2. The table indicates that the natural clay is alumino-silicate containing about 51% SiO_2 and 40% Al_2O_3 and also has an iron content of 0.03 wt %. Loss on ignition is very negligible so are combined oxides of CaO, $TiO_{2,}$ and MgO having values less than 0.1%. In a comparison of standard classification established, the clay could be classified as siliceous acidic clay. But the amount of NaO_2 and K_2O at a combined composition of 8% is probably quite high and outside the limit available in the literature.

Figure 2: MPKS/Cement samples at different ratios

Figure 3: MPKS/Clay samples at different ratios

In Fig. 2 and 3, the physical images of the prepared block samples for MPKS/cement and MPKS/clay are displayed respectively. It is, however, observed that the samples have different appearances. This is attributed to the increase in aggregate as well as the treatment of the PKS.

4.0.1 Moisture content (MC)

Figure 4: Moisture content against filler ratios

Samples 40/60 and 80/20 blocks in Fig. 4 have the highest MC rate due to the lack of insufficient bonding relationship between the modified PKS particles and binder. It could also be that the presence of more macro-crack as a result of increasing filler content in the mixture process might have led to the increase in atmospheric moisture rate for both cement and clay block samples. Sample (20/80) had the lowest rate of 4.7% and 10.2% for MPKS/cement and MPKS/clay respectively due to the high percentage of the mortar in the mixture as well as low filler content which creates better network structure in the process [29].

4.0.2 Water Absorption (WA)

Figure 5: Water absorption against filler ratios

Figure 6: Apparent porosity against filler ratios

Sample 20/80 for both MPKS/cement and MPKS/clay blocks in Fig. 5 indicates a better WA resistance of 8.6% and 11.1% respectively. This could be as a result of the less porous condition of the samples which limits the permeation of water into the samples; causing a decrease in percentage thickness swelling of the agro-waste (MPKS) filler and having better dimensional stability due to the high mortar rate in the mixing process. Compared to samples like 60/40 and 80/20 with the highest absorption rate of 32.5% and 49.5% for MPKS/cement blocks while that of MPKS/clay dispersed completely within some minutes contact with water. This high percentage rate is adverse since it can lead to collapse, swelling, disorder, and weaker bonding when used for construction purposes. This result statistically confirms the report of the work by [30, 31]. Furthermore, this WA trend can be related to the AP rate as shown in Fig. 6.

4.0.3 Microhardness (MH)

Figure 7: Microhardness against filler ratios

In Fig. 7, sample 20/80 for both MPKS/cement and MPKS/clay blocks exhibit the highest MH rate of 82 and 69.3 Hv respectively. This may be due to higher compactness, minimize pores, and better interlocking between the individual aggregates and binder which could directly have a positive impact on the mechanical strength of the samples. These results also reveal that the MH decreases with an increasing filler content up to 80/20 ratios. The filler and the binder content are the major factors affecting the MPKS block production. This distinctly contributes to the hydration process, thereby chemically transforming cement material from not only being a fine dry powder but to a hard-binding paste. Samples 60/40 and 80/20 being the weakest had MH rates of (57.2 and 59.8 Hv) and also (45.7 and 50.1 Hv) for MPKS/cement and MPKS/clay blocks respectively due to its less dense properties and poor bonding of the aggregates which could cause easy dispersion when samples undergo simple stress. The result got, agrees with the research of [32].

4.0.4 Bulk Density (BD)

Figure 8: Bulk density against filler ratios

Figure 8 graph, shows a gradual decrease across the various filler ratios up to sample 80/20. This could be as a result of a reduction in particles/binder compactness leading to an increase in internal pores and as well making the block especially for 60/40 and 80/20 less dense, more porous, and of low strength. With this filler addition, the stiffness and mechanical strength of the blocks are negatively affected due to the nature, structure, and physical characteristics of MPKS. Sample A of ratio 20/80, reveals the optimum bulk density value of 2.9 g/cm^3 for MPKS/cement, higher than the 2.5g/cm^3 recorded by [33]. This could be attributed to the upgrade in the adhesion between the cement and the MPKS which also exhibits a pragmatic connection with compression strength. Furthermore, the change in weight of the binder to the total volume is the sum of both compacted and open pores. In other words, the rise of bulk density is a result of the compactness of internal pores which limits the effective volume of the material. This authenticates the statement by [34], that the more closely packed the particles in the material the higher the density. Also, it compares well with the report of [35] based on palm kernel shells as coarse aggregate in concrete.

4.0.5 Compressive strength

Figure 9: Compressive strength against filler ratios

The compressive strength (CS) graph shows that Sample 20/80 displayed the best strength of 63.72 and 50.3 N/mm^2 for MPKS/cement and MPKS/clay blocks respectively. This is in agreement with results reported by [36], that optimum CS is attainable for 10%-40% PKS addition. The high CS for 20/80 MPKS/cement and MPKS/clay could be due to the modification of the aggregate, as effective stress transfer is achieved as a result of enhanced interfacial adhesion. The minimum compressive strength according to NIS 87 (2000), of non-load bearing blocks is 2.5 N/mm^2. This indicates that (60/40 and 80/20) blocks especially for (MPKS/cement) will fail slowly with significant distortion. Similar results were reported by [32, 35, 37].

4.0.6 Flaking

Figure 10: Flaking against filler ratios

Figure 10, shows a gradual increase in flaking up to sample 80/20. This may be as a result of a poor fusion of the mortar, high filler content, as well as high inner pores in samples 60/40 and 80/20 with a very high flake rate of 0.18 and 0.21 g for cement and 0.23 and 0.28 g for clay blocks respectively. Compared to sample 20//80 with better network structure, stronger bond, higher bulk density, and lesser flaking of 0.03 and 0.06g for MPKS/cement and MPKS/clay blocks respectively. This result statistically agrees with the report by[11],31]

4.0.7 Scanning Electron Microscope (SEM) Analysis

Figure 11: (a) SEM image for sample A (20/80) MPKS/Cement (b) SEM image for sample A (20/80) MPKS/Clay (c) SEM image for sample C (50/50) MPKS/Cement (d) SEM image for sample C (50/50) MPKS/Clay (e) SEM image for sample E (80/20) MPKS/Cement (f) SEM image for sample E (80/20) MPKS/Clay

Samples 20/80, 60/40, and 50/50 for MPKS/Cement and MPKS/Clay from Fig. 11 show the various bonded areas, de-bonded areas, and internal pores or cracks present in the different filler ratios. However, sample 20/80 for MPKS/cement and MPKS/clay blocks (Fig. 11(a) and (b)) exhibits much larger bonded areas, smaller pores, and fewer de-bonded areas compared to samples 50/50 and 60/40 blocks for MPKS/cement and MPKS/clay Fig. 11 (c), (d) and (e), (f)) respectively. This attraction between masses indicates a firm bond between them, thus inhibiting dispersion as a result. Sample (50/50) block for MPKS/cement and MPKS/clay (Fig. 11(c) and (d)) reveals fewer micro-cracks, fewer de-bonded areas, and better-bonded areas due to a fair fusion between the binder and modified particles [29]. This exhibits a moderate non – dispersive appearance where the particles can be seen forming tight edge-to-face (EF) and edge-to-edge (EE) flocculation. Sample 80/20 block for MPKS/cement and MPKS/clay (Fig. 11(e) and (f)) displayed very few bonded areas, much de-bonded areas, and larger pores due to continuous addition of MPKS aggregates which resulted in poor fusion and high rough surfaces. Interestingly, filler addition was accompanied by decreased stiffness and mechanical strength of the developed blocks. When water comes in contact with such block bonds, easy dispersion could occur.

5.0 Conclusion

From the results obtained in this study, the 20/80 ratio represented by sample A both for MPKS/cement and MPKS/clay blocks exhibited the best physicomechanical and morphological properties compared to other represented blocks; as a result of tight network structure, the stronger bond within the particles, and a high percentage of mortar. Though the MPKS/clay blocks present comparable values to that of the MPKS/cement samples at all ratios they could also be recommended for non – load-bearing construction up to a ratio of 50/50. In comparison to prior studies, the MPKS/cement samples, particularly for 20/80 (Sample A), had superior characteristics, resulting in improved performance and applicability as reinforced cement composites. Because PKS is locally sourced and readily available, it is believed that its usage as a partial replacement or alternative aggregate material in block manufacturing will significantly lower building costs in Nigeria and, by extension, other developing countries.

Declarations

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Conflict of Interest/Competing interest

The authors declare that they have no conflict of interest.

Availability of data and material

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study

Code availability

Not applicable

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Figures

Figure 1

(a) Dried PKS (b) Ground PKS (c) Ordinary Portland cement (OPC) (d) Clay powder (e) Cylindrical mould

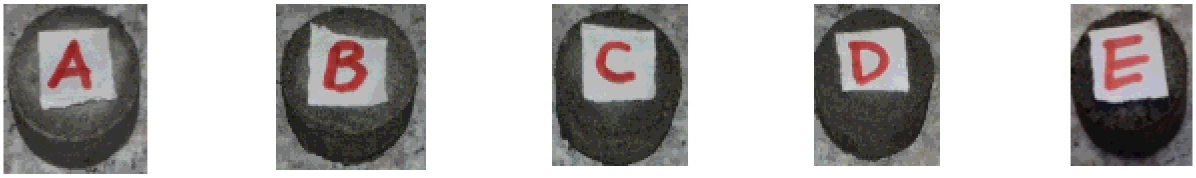

Figure 2

MPKS/Cement samples at different ratios

Figure 3

MPKS/Clay samples at different ratios

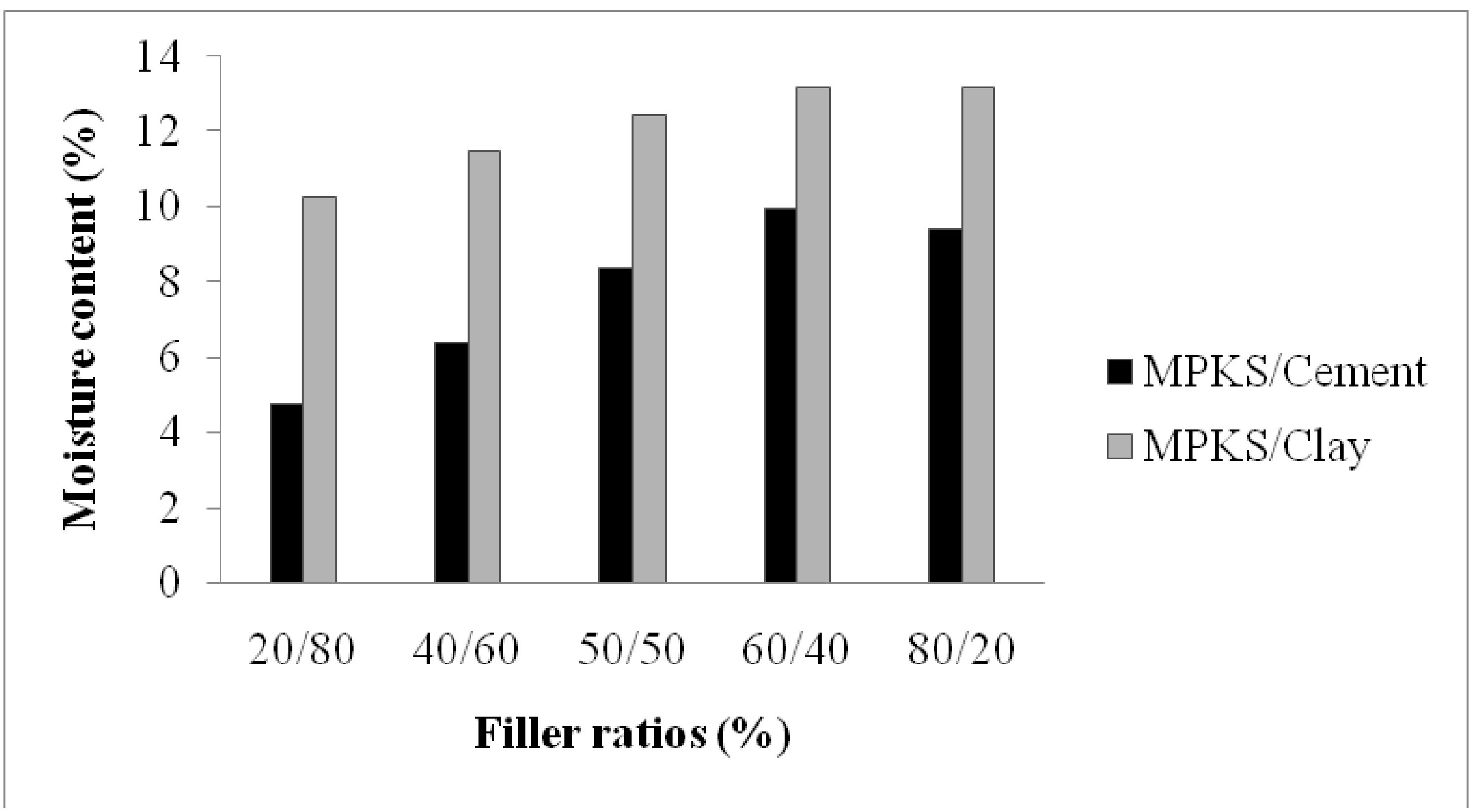

Figure 4

Moisture content against filler ratios

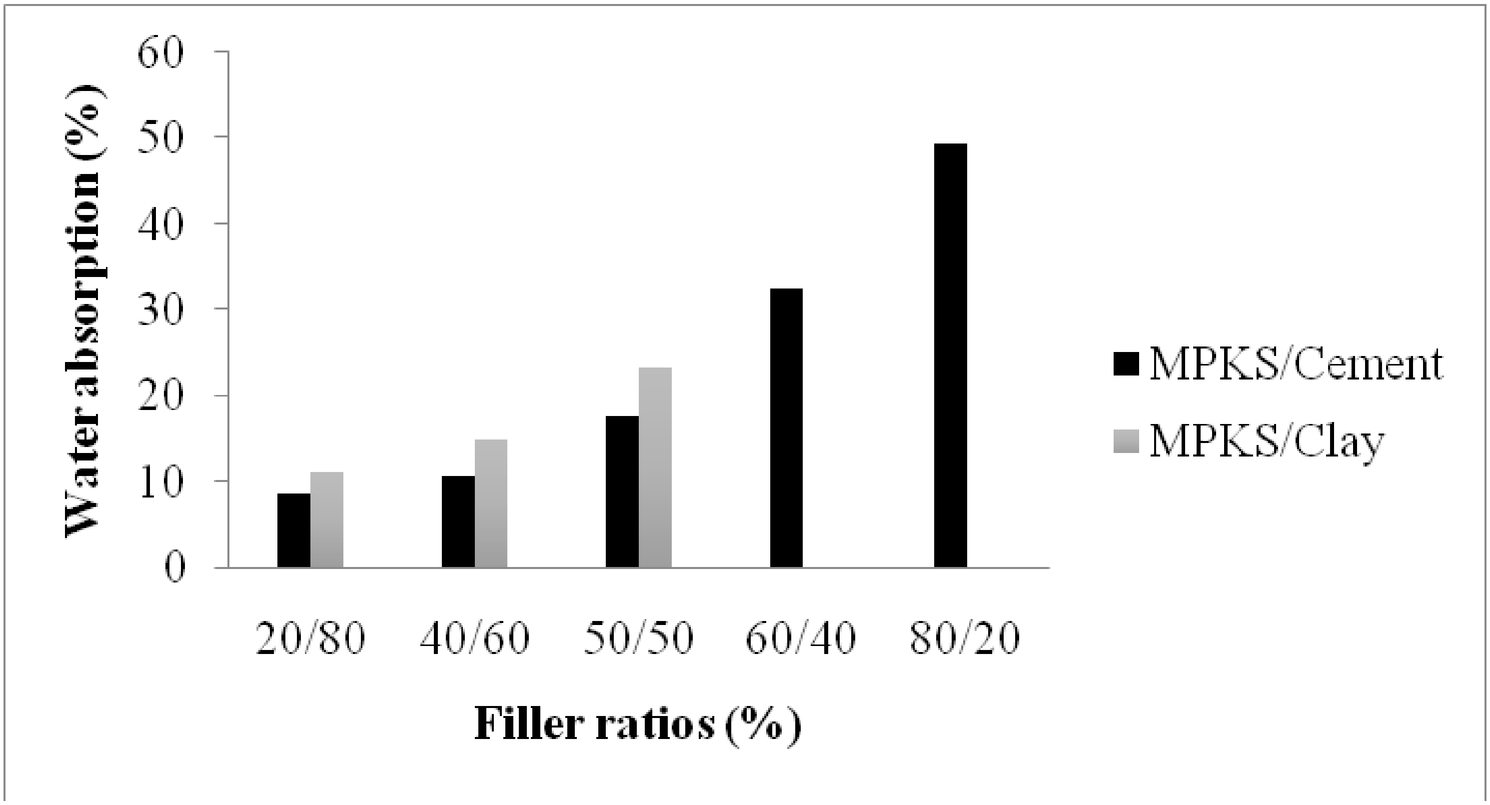

Figure 5

Water absorption against filler ratios

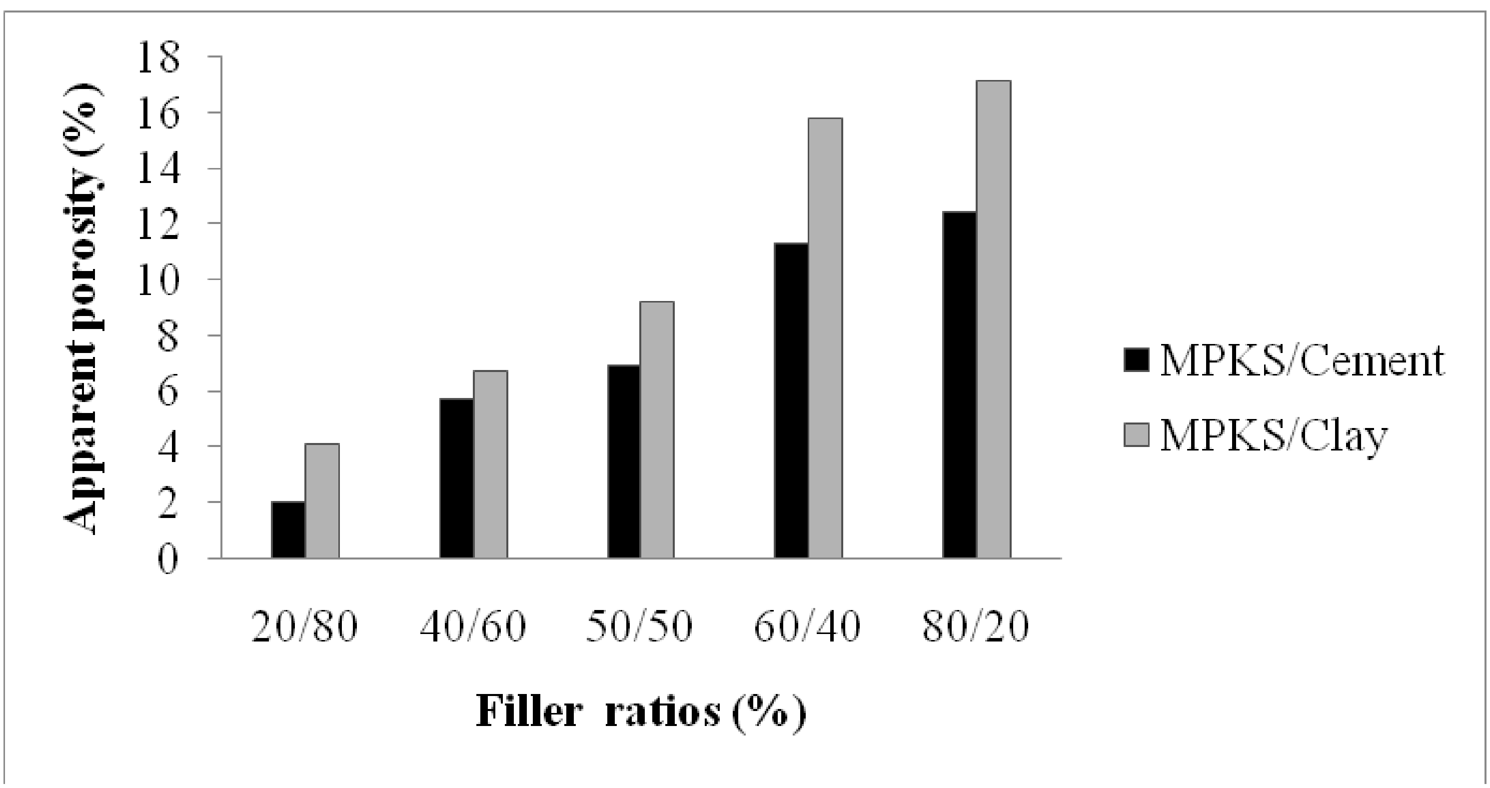

Figure 6

Apparent porosity against filler ratios

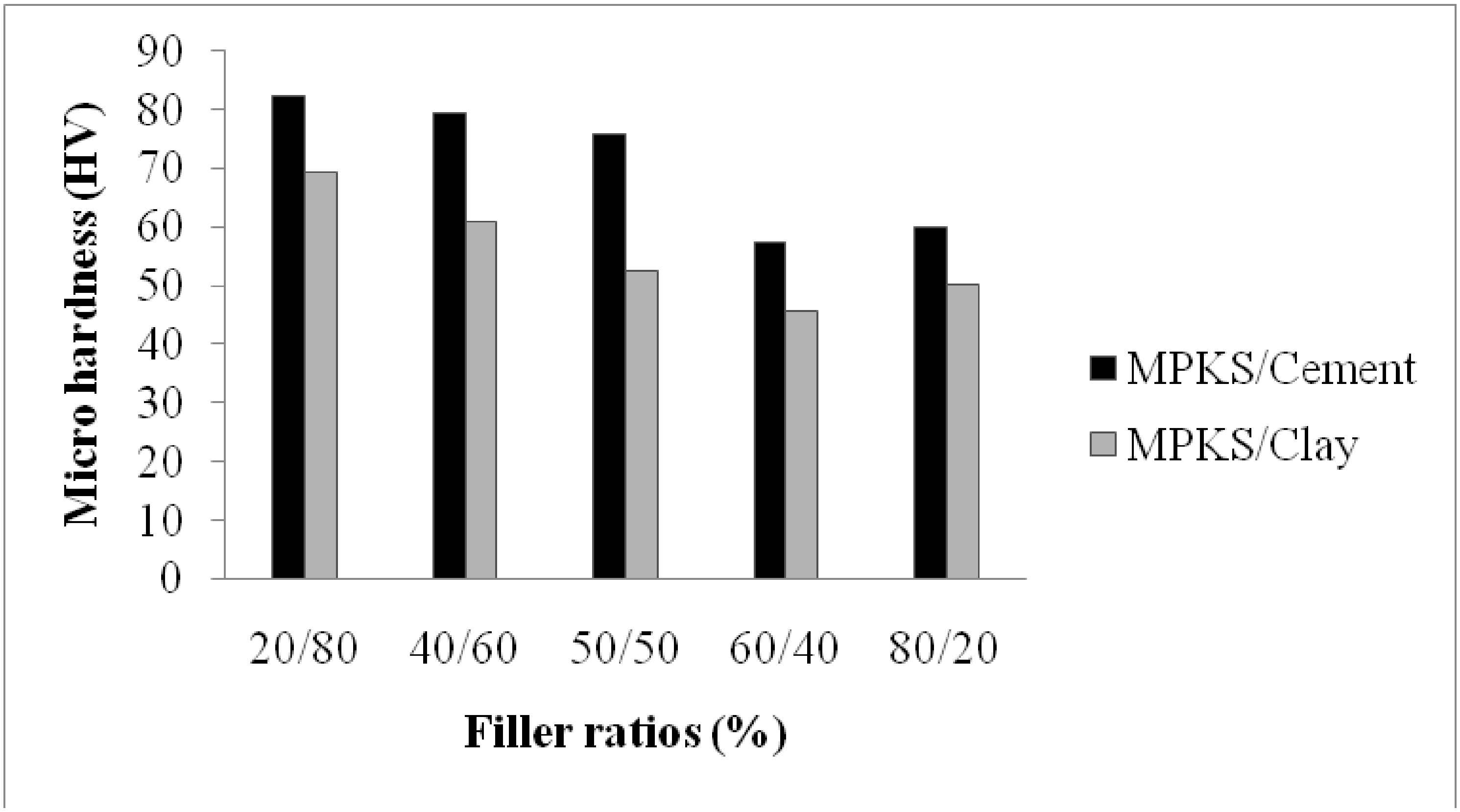

Figure 7

Microhardness against filler ratios

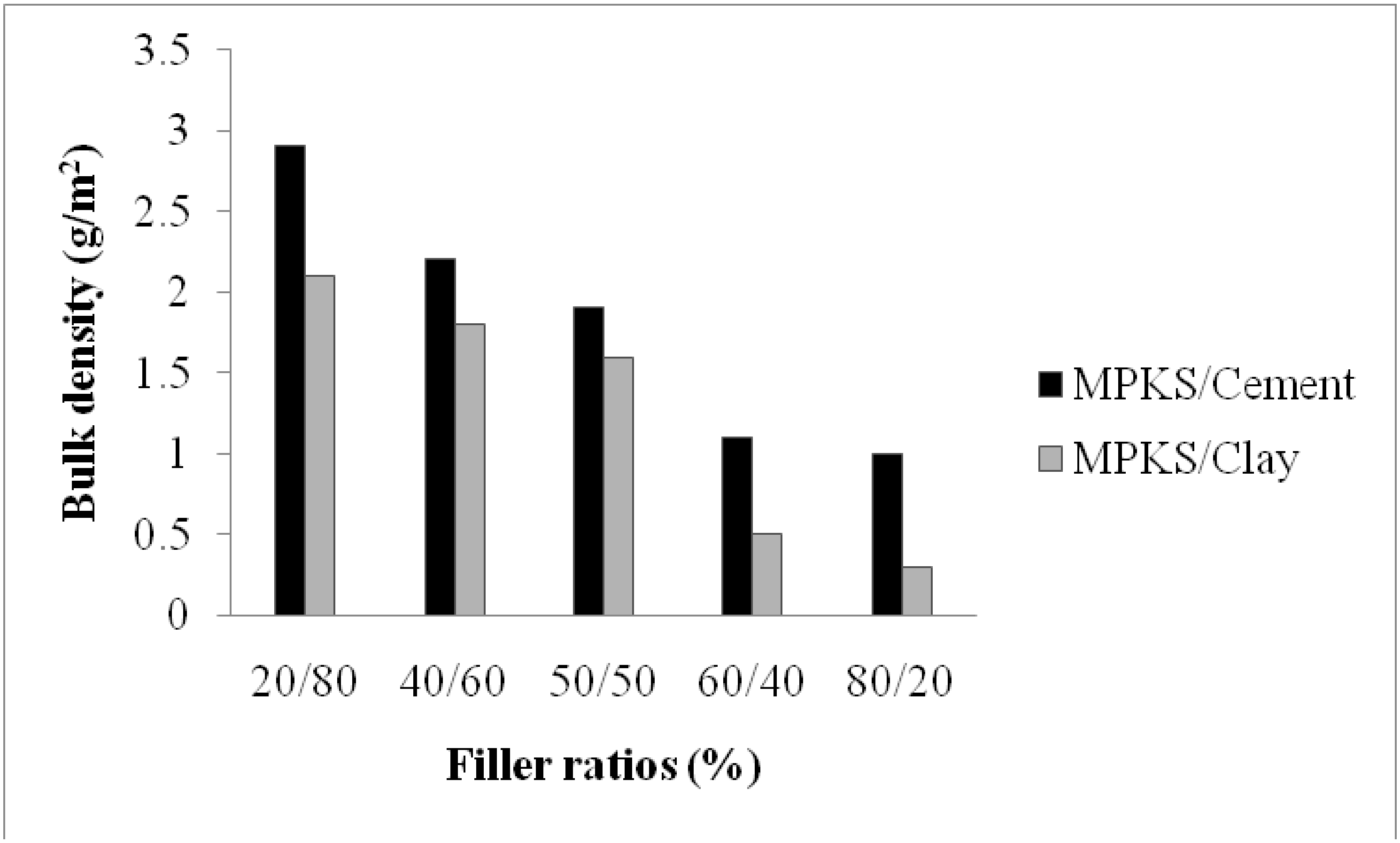

Figure 8

Bulk density against filler ratios

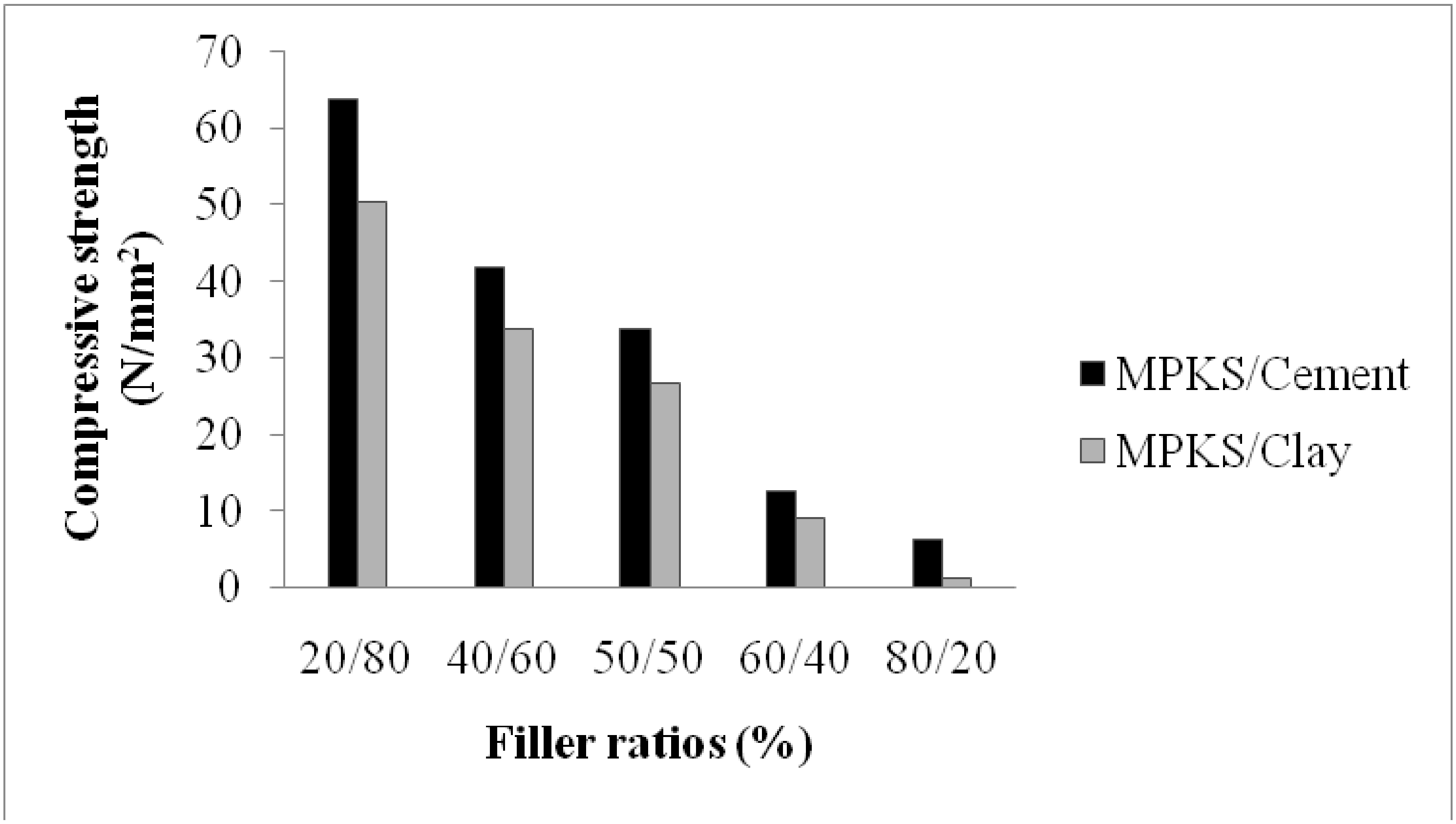

Figure 9

Compressive strength against filler ratios

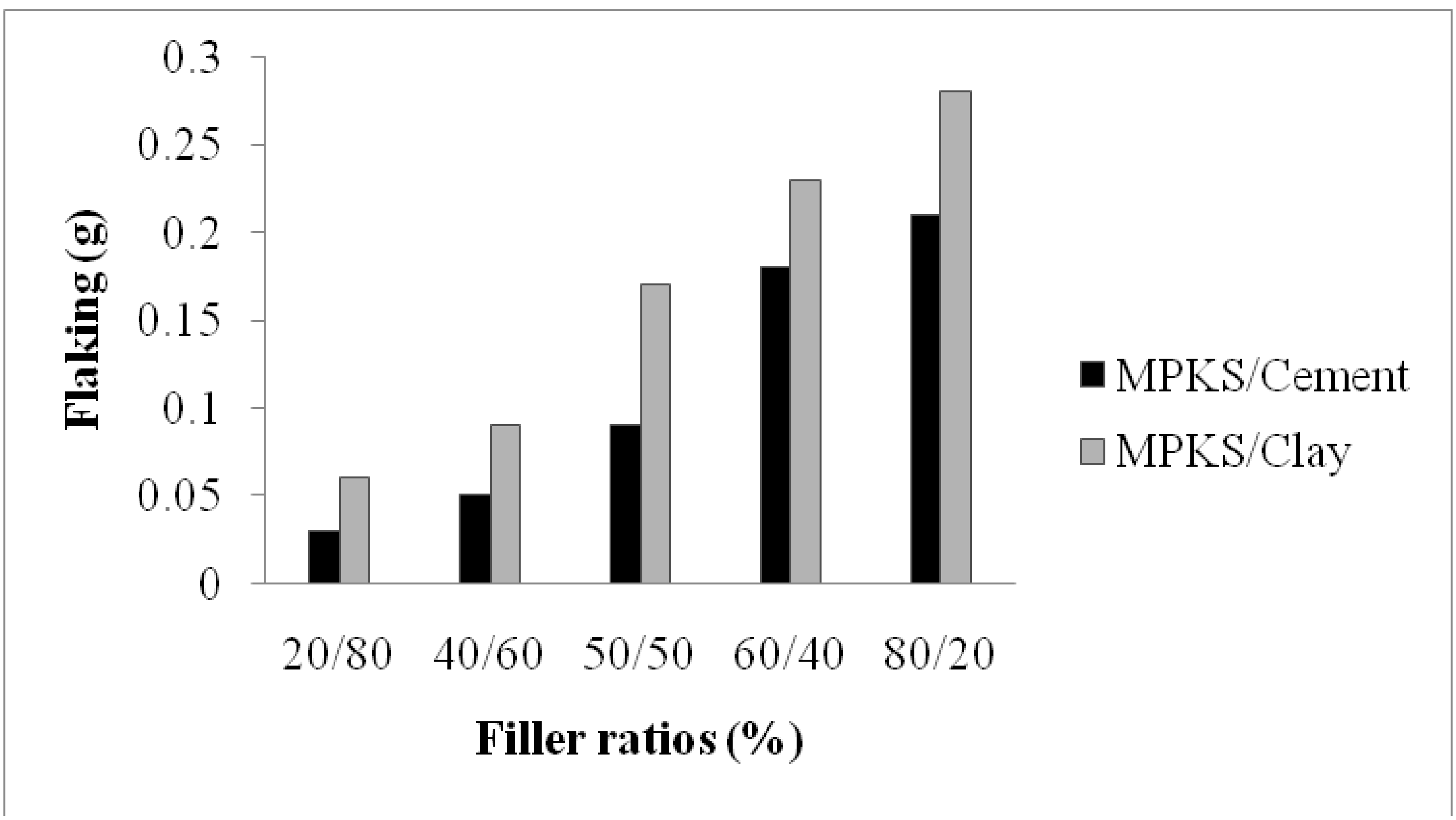

Figure 10

Flaking against filler ratios

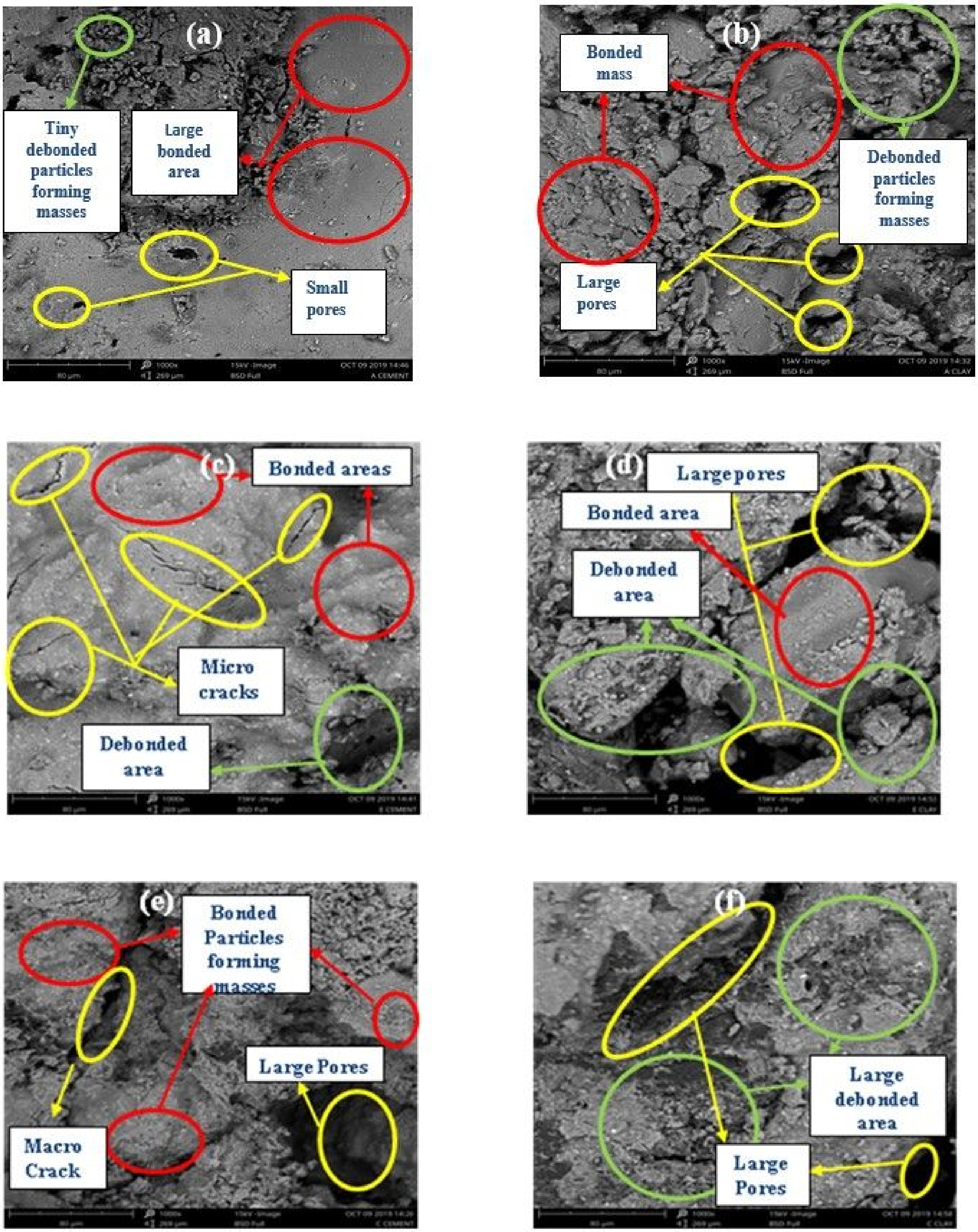

Figure 11

(a) SEM image for sample A (20/80) MPKS/Cement (b) SEM image for sample A (20/80) MPKS/Clay (c) SEM image for sample C (50/50) MPKS/Cement (d) SEM image for sample C (50/50) MPKS/Clay (e) SEM image for sample E (80/20) MPKS/Cement (f) SEM image for sample E (80/20) MPKS/Clay