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PROPERTIES OF REACTIVE POWDER CONCRETE PRODUCED WITH UNREFINED METAKAOLIN AND GEAR INNER WIRE

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With the soaring need to use innovative and sustainable materials in the construction industry, a new concrete known as Reactive Powder Concrete (RPC) is currently a material of significant interest globally. The concrete constitutes cement, silica fume (SF), fine sand, quart sand and fibre as its ingredients. However, the importation of SF and fibre is making RPC production relatively expensive in Nigeria due to their non-availability. This paper examines the effects of unrefined Metakaolin (MK) as substitute to silica fume and Gear Inner Wire (GIW) as fibre on the properties of RPC. RPC specimens produced with up to 30% MK by weight of cement, and a constant GIW content of 0.25% by weight of concrete were subjected to compressive strength, tensile strength and flexural strength tests. Similarly, RPC produced with 20% silica fume as reference was tested. Unrefined MK and GIW have been found to be suitable in the production of RPC. Unrefined MK performs in similar way or slightly better than SF in terms of compressive, tensile and flexural strengths. The GIW positively affect the tensile and flexural strengths of the RPC but negatively affect the compressive strength. The results show that 20% unrefined MK is the optimum content for producing RPC with the compressive, tensile and flexural strengths values of 64.5N/mm2, 4.7 N/mm2 and 18.7 N/mm2 respectively as confirmed by the XRD and SEM results. The use of the unrefined MK and GIW can lead to production of cheaper and sustainable RPC by cutting down importation cost of SF and fibre materials.

Keywords: gear inner wire, strength, reactive powder concrete, un-refined metakaolin

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INTRODUCTION

Many research works have been undertaken over the years aimed at achieving high mechanical performance with cementitious matrix materials (Chana, Luo & Sunb, 2000; Aitcin, 2003; Momtazi, Ranjbar, Balalaei & Nemati, 2007; Maroliya & Modhere, 2010; PatilS, Gupta & Deshpand, 2013; Shan, Rijuldas & Aiswarya 2016). Such development of an ultra-high strength and ductile concrete called Reactive Powder Concrete (RPC) was first made possible by Richard and Cheyrezy in 1995. It is produced by the application of a certain number of basic principles relating to the composition, mixing and treatment of the concrete.

RPC was developed through microstructure enhancement techniques for cementitious materials which include eliminating coarse aggregates, reducing the water-to-binder ratio, lowering calcium oxide (CaO) to silicon oxide (SiO2) ratio by introducing the silica components and incorporating steel micro-fibres to improve its ductility (Yazici, Yardimci, Aydin & Karabulut, 2009). There are a lot of researches carried out across the globe which indicate that RPC is a future concrete material because of its high mechanical properties.

RPC has a compressive strength of more than 170N/mm2, flexural strength of up to 60N/mm2 (Richard & Cheyrezy, 1995) and tensile strength of up to10N/mm2 (Qureshi, Tasaddiq, Ali & Sultan, 2017) using silica fume as the pozzolan. It was stated that a compressive strength of 80N/mm2 and flexural strength of 20 N/mm2 was achieved using local materials available in Pakistan. Because of its high strength, RPC is a brittle material requiring the incorporation of steel fibre to enhance its tensile and flexural strengths. It exhibits varied compressive strength when cured under different conditions.

RPC were examined under different curing regimes and the results indicated that the compressive strength at 28 days varied between 170 N/mm2 and 202 N/mm2 for heat treated specimens; up to 400 N/mm2 for autoclaving and between 130 N/mm2 and 150 N/mm2 for non-heat treated specimens (Cwirza, Penttala & Vornanen, 2008; Maroliya 2012; Yazici et al., 2009; Tam, Tam & Ng, 2010; Yazici, et al. 2010). However, the use of cement in conventional RPC is high and silica fume (SF) content is up to 25% (by weight of cement). Haghighi, Koohkan, and Shekarchizadeh (2007) states that the optimum amounts of SF in RPC might be 20% or 25%. Hiremath and Yaragal (2017) used 20% SF as optimum. However, 20%SF will be more appropriate due to its cost and non-availability in some developing countries like Nigeria. Other shortcoming of SF is increase heat of hydration which causes shrinkage problems (Peng et al., 2015). Moreover, steel fibre used in the RPC is also not available in Nigeria. The non-availability of these two major materials of RPC is becoming worrisome to the Nigerian construction industries as they have to battle between importation cost and delivering projects at an acceptable price to their clients.

Therefore, using other mineral admixtures in the production of the RPC has been proven to be a feasible solution to the problems of SF (Rougeau & Borys, 2004; Yazici et al., 2009; Yazici et al., 2010; Agharde & Bhalchandra, 2015; Kushartomo et al., 2015). When fly ash was used to replace SF in RPC, compressive strength of between 62.9 N/mm2 to 324N/mm2 and a flexural strength of 8.8 N/mm2 to 32 N/mm2 were obtained (Yazıcı, Yigiter, Karabulut & Baradan, 2008; Yazici et al., 2009; Ding, 2010; Demiss, Oyawa & Shitote, 2018). A compressive strength of 128 N/mm2 to 250 N/mm2 and a flexural strength of between 25.6 N/mm2 to 32 N/mm2 were obtained with ground granulated blast furnace slag (Yazici et al., 2009; Peng, Hu & Ding, 2010; Nguyen et al., 2011). Also, Asteray, Oyawa and Shitote (2017) observed that a 28 day's compressive strength of 57.3 N/mm2 was achieved when rice husk ash was used to replace the SF in the production of RPC.

Moreover, some materials were used as fibre in the production of mortar and concrete in areas where conventional fibres are not available and have proved to be effective. Foti (2013) and Pereira de Oliveira and Castro-Gomes (2011) investigated the effect of waste polyethylene terephthalate (PET) as fibres in concrete and mortar respectively. Results showed that the incorporation of the PET fibres significantly improves the flexural strength and toughness of the prepared specimens. Waste steel recovered from milling and machining was used as steel fibre in concrete production. Outcome of the experiment indicates improvement of the fragile matrix, mostly in terms of toughness, energy absorption and post-cracking behaviour (Jalal, 2012). Study on the influence of adding waste materials like lathe waste, soft drink bottle caps, empty waste tins, waste steel powder from workshop at a dosage of 1% of weight of concrete as fibres was undertaken by Murali et al. (2012). The materials were deformed into rectangular strips of 3mm width and 10mm length. It was revealed that a concrete block incorporated with the steel powder has increased compressive strength by 41.25% and tensile strength by 40.81% while concrete made with the soft drink bottle caps exhibited an increased flexural strength by 25.88%. More recently, Ibrahim, Garba, Usman and Gambo (2018), used waste gear inner wire as fibre (WGIW) in mortar production. Results showed that the fibre mortar sample has higher compressive and tensile strengths at 56 days by 19% and 21.1% respectively then the non-fibre one and concluded that WGIW at 2% volume fraction could be used as fibre in mortar production. WGIW are gear inner wire (GIW) materials mean for bicycle brakes which are disposed after use. But WGIW or GIW (un-used or new one) may behave differently when used in concrete particularly special concrete like RPC. This could be due to the fact that GIW is not a standard fibre material used in concrete, but rather, improvised one.

However, for RPC to be produced in Nigeria there is the need to find similar, available and alternative material to SF and steel fibre in terms of performance. These ways, the costs of producing the concrete can be reduced by cutting down importation cost. MK has been found to perform similar to SF on the properties of concrete and is used in the same manner (ACI 232.1R-00). MK improves tensile strength and bond strength (Vipat & Kulkarni, 2016) and up to 8%MK enhances tensile strength (Haroon, Ashad, Vikas & Alvin, 2017) of concrete but 10% has been reported by Badogiannis (2005) to be more favourable. Moreover, Justice and Kurtis (2007) reported that MK behaves differently from other pozzolan like SF, fly ash, etc. due its high reactivity with calcium hydroxide and its influence in increasing cement hydration. There are large deposits of kaolinitic clay from which MK is obtained across Nigeria (Ibrahim, Okoli & Dahiru, 2014). Smith, Gururaj and Siddesh (2015) recorded savings when 15% of the SF was partially replaced with commercial (refined) MK in the production of RPC. In normal concrete, unrefined MK has been shown to improve the strength and durability properties of concrete similar to the refined one (Badogiannis & Tsivilis, 2009). According to Shafiq, Nuruddin, Khan and Ayub (2015) the performance of locally produced MK (unrefined one) is similar or slightly better than commercially available SF in terms of strengths and pozzolanic activity. Therefore, further savings and performance (compare to using silica fume) can be realised if the refined MK is replaced with the unrefined one in the production of RPC. The Nigeria's large deposits of kaolinitic clay may be used to produce the unrefined metakaolin. Therefore, this research focused on evaluating the properties of RPC with GIW and locally sourced unrefined MK. Using the unrefined MK further reduced the cost of producing the RPC by eliminating refining and beneficiating process associated with refined MK.

MATERIALS AND METHODS

Materials

The cementitious materials used for this research are cement; unrefined metakaolin (MK) and densified silica fume (SF). The cement used is Dangote brand of Portland Limestone that satisfied the requirements of BS EN 197-1:2011. Unrefined MK was produced by heating raw kaolin at 750oC for 2 hours in an electric furnace. The kaolin was sourced from a kaolinitic clay deposit situated in Getso, Kano State. It can be observed from Figure 1 that the calcined kaolin has reduced peak than the kaolin (K & Q). The 2θ value (between 20 -30) shows hallow in shape in the calcined kaolin indicating that the material (MK) used in the research has been transformed from crystalline to amorphous phase (Badogiannis, Kakali & Tsivilis, 2005; Wang, Li & Yan, 2005). The silica fume was supplied from Malaysia. The chemical composition and physical properties of the cementitious materials are presented in Table 1. Based on its chemical compositions and physical properties, the MK can be classified as N- Class pozzolan as recommended in ASTM C 618. Water fit for drinking which satisfies the requirement of BS EN 1008:2005 was used for mixing and curing off the RPC specimens. Gear Inner Wires (GIW) means for bicycles brakes were cut into pieces (Figure 2) and used as fibre. The GIW are characterised by same length and different diameters of 0.28mm, 0.32mm and 0.39mm which were determined using ruler and digital vernia calliper respectively. The tensile strengths were determined using tensor meter. The GIW with highest aspect ratio (43) compared to other samples was selected and used in the entire experiment. The aspect ratio is the ratio of the length (L) to the diameter (D). The geometry of the fibre is shown in Table 2. Polycarboxylate ether based super plasticiser (Conplast SP 430) conforming to ASTM C 494 was used to achieve the required consistency of the mixes. Naturally occurring river sand with particle sizes of 600μm - 150μm and absorption of 4% was used as fine aggregate.

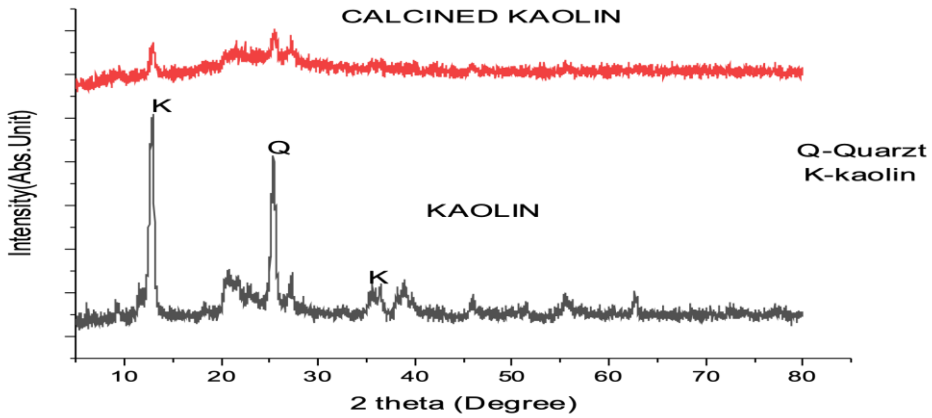


Figure 1: XRD result of Metakaolin

Table 1: Oxide c compositions and physical properties of RPC constituents

Oxide (%)	Sand	Cement	Silica fume	Metakaolin
SiO2	86.53	17.519	92.00	65.05
Fe2O3	2.94	2.768	0.50	2.59
Al2O3	1.64	4.74	0.70	20.65
CaO	0.40	71.297	0.50	0.82
CuO	0.00	0		0.02
NiO	0.00	0	0.015	0.03
MnO	0.01	0.072	0.128	0.08
Cr2O3	0.00	0	0.006	0.03
TiO2	0.00	0.105	0.071	0.00
MgO	0.60	0	0.50	1.66
SO3	0.10	0.00	0.00	0.18
ZnO	0.00	0.007	0.006	0.01
SiO2 + Al2O3 + Fe2O3				88.29
LOI	0.84	3.492	3.00	1.80
Physical properties				
Surface area (m2 /kg)		561.9	2 0, 000	509.0
Strength activity index (%)			-	87
Specific gravity			2.21	2.53

Table 1 shows the chemical compositions and physical properties of the constituent materials of RPC. For unrefined MK, the summation of the major oxides (SiO2 + Al2O3 + Fe2O3) is 88.29% which is above the minimum (70%) specified by ASTM C 618-05 for class N pozzolanic materials. The results of Dangote blended cement and silica fume are also shown on Table 3. Moreover, the surface area of the cement, MK and SF are 561.9m2/kg, 509m2/kg and 20000 m2/kg respectively. It can be observed that the SF has the highest surface area while MK has the lowest. This means that the SF is finer than the MK which could lead to more water or superplasticizer requirement (Khan, Nuruddin, Ayub & Shafiq, 2014).


Roll of GIW GIW after cutting

Figure 2: Sample of the GIW as fibre

Table 2: Properties of Gear Inner Wire (GIW) as Fibre

S/No.	Diameter (mm)	Length(mm)	Aspect ratio (L/D)	Tensile strength (N/mm^2)
1.	0.28	12	43	1623
2.	0.32	12	38	1888
3.	0.39	12	31	1657

Mix proportioning

Mix design of the RPC produced evolved from several trials due to the absence of an established design method. However, the formulation used by Richard and Cheyrezy (1995) was adopted as a basis for the trial and error.

Table 3: Mix proportion of RPC specimens

Specimen ID	20SF	10MK	20MK	30MK	20SF	10MK	20MK	30MK
	Non fibred				Fibred			
Cement	1	1	1	1	1	1	1	1
Silica fume	0.20	0	0	0	0.20	0	0	0
Metakaolin	0	0.10	0.20	0.30	0	0.10	0.20	0.30
Sand (150-600µm)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Crushed quartz	-	-	-	-	-	-	-	-
Superplasticizer	3.5	2.8	3.8	4.5	3.6	3.2	3.9	5.0
(GIW) L=12mm	-	-	-	-	0.02	0.02	0.02	0.02
Water	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Comp. press.	-	-	-	-	-	-	-	-
Heat treatment temp. (°C)	27	27	27	27	27	27	27	27

Note: Cement Content = 900kg/m3; Fibre Content= % of weight of concrete, SP content=% of binder

The ingredients used in this study for the control mix of RPC include cement, silica fume, fine sand, GIW as fibre, superplasticizer, and water. The specimens were then produced by totally replacing the SF content with unrefined MK. The MK was used in different percentages (10%, 20% and 30%) of the weight of cement. Quartz powder was not used in the experiment because it is only used for heat-treated RPC (Richard & Chereyzy, 1995). The mix proportions of the RPC specimens are presented in Table 3. Different mixes were labelled for identification based on the type and content of the pozzolanic material used in their production. For instance, 20SF means, the specimen was produced with 20% silica fume (SF), 10MK, 20MK and 30MK means that the specimen was produced with 10%, 20% and 30% metakaolin (MK) respectively.

Specimen's preparation

To prepare the specimen, the cementitious materials were dry mixed in a mortar mixer for about one minute at low speed of 10 rpm. Water (about 80% of the mixing water) and superplastizer in the range of 2.8% to 5.0% were added to the mixture and the mixing continued for three minutes at medium speed (140 ± 5 rpm). Fine sand and GIW fibre were then added to the mixture and mixing continued for another four minutes. The remaining water (about 20%) was then added to the mixer and mixed at high speed (285 ± 10 rpm) for additional four minutes. Finally, the mixer was then returned to the medium speed (140 ± 5 rpm) and mix for three minutes. This mixing method was adopted from Hiremath and Yaragal (2017). All the fresh mixes had consistency of 270±5 mm. After mixing, the fresh specimens were cast and kept in moulds for 24 hours in the laboratory condition (27 ± 2oC). Cube moulds of 50x 50 x 50 mm, cylindrical moulds of 50mm diameter and 100mm height and prismatic moulds of 40x40x160mm were cast as the specimens for compressive strength, split-tensile strength and flexural strength tests, respectively. Specimens were then taken out from the moulds and cured in water until the testing ages of 7, 14 and 28 days.

Testing methods

Flowability

The flowability test of the RPC was conducted by filling a mini-slump cone in accordance with ASTM C1611. The cone was then carefully removed to allow the mix to flow under the influence of gravity as RPC is considered to be self-flowing concrete (Figure 3). ASTM C143 (AASHTO T119) states that for concrete to be regarded as self-compacting concrete, the flow value or workability of such concrete should be ˃ 190mm and ≤600mm (ASTM C1611). Therefore, it was based upon this range and series of trials that the flow value of the RPC produced was fixed at 270±5mm. This value was achieved by the addition of superplasticizer. The flow of the mix was obtained by measuring the spread using a measuring tape. Average of four measurements of the spread was reported for each mix (Figure 2b).

Figure 3: Flowability of RPC

Strength properties

Compressive strength, split-tensile strength and flexural strength tests were carried out in accordance to BS EN 12390-3:2002, ASTM C496 and ASTM C78 specimens respectively. For the compressive strength, cube of the specimens were loaded in uniaxial compression using standard procedures for cube testing in a 1500 KN universal testing machine. The load was applied with a constant loading rate of 0.4 N/mm2/s during the entire test period until specimens failed. The split tensile strength was also tested on the same machine. Flexural strength was tested using third points loading on prisms. The average of three measurements was reported for each test.

Microstructure analysis

Microstructure analysis was carried out using X-Ray Diffraction (XRD) which was used to identify the compounds and minerals present in kaolin, MK and powdered RPC specimens. The XRD was carried out on the kaolin and the calcined kaolin (Figure 3) to ensure that the temperature and time used during the calcination was sufficient enough for the conversion of the kaolin from crystalline to amorphous phase. On the other hand, Scanning Electron Microscope (SEM) technique and XRD were used on the powdered RPC specimens to identify the morphology of the structure, compound and minerals in the RPC. The SEM and XRD were only conducted on powdered RPC specimens with highest and lowest strength, so also, on the reference sample (20%SF).

RESULTS AND DISCUSSIONS

Flowability of RPC

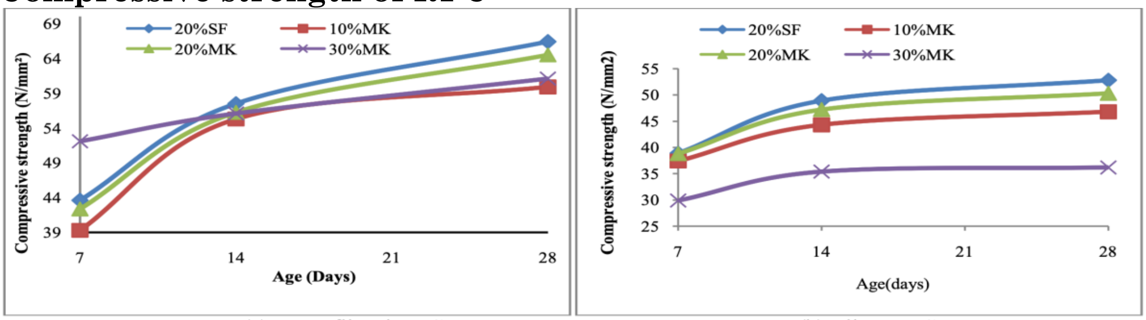
Table 4 shows the flow values of the various RPC specimens. Result shows that in order to achieve the 270±5mm flow value for the control specimens (20%SF) of the RPC, up to 4% superplasticizer (SP) was added to the mix. For the MK specimens to achieve the 270±5mm flow value, 10%MK requires 2.8%, 20%MK requires 3.7% and 30%MK requires 5% of the SP. There is around 30% and 7.5% reduction in the quantity of SP required by 10%MK and 20%MK compared to the control (20%SF) respectively. For the same percentage (20%), SF demands higher SP than MK (Meddah, Ismail, El-Gamel & Fitriani, 2018). However, there is 20% increase in the quantity of the SP required by 30%MK compared to the control. The higher demand of SP by 20%SF compared to

10%MK and 20%MK could be due to the high surface area (20000 m2/kg) of the SF. But for 30%MK, the higher demand of SP compared to the 20%SF could be due to the higher percentage of the MK (Khan, Nuruddin, Ayub & Shafiq, 2014).

Table 4: Flow value of RPC specimens

Specimens	Amount of SP used (%)	Target flow value (mm)	Flow value obtained (mm)
20%SF	4	270±5	267
10%MK	2.8	270±5	271
20%MK	3.7	270±5	269
30%MK	5	270±5	273

Compressive strength of RPC



(a) Non-fibred RPC (b) Fibre RPC

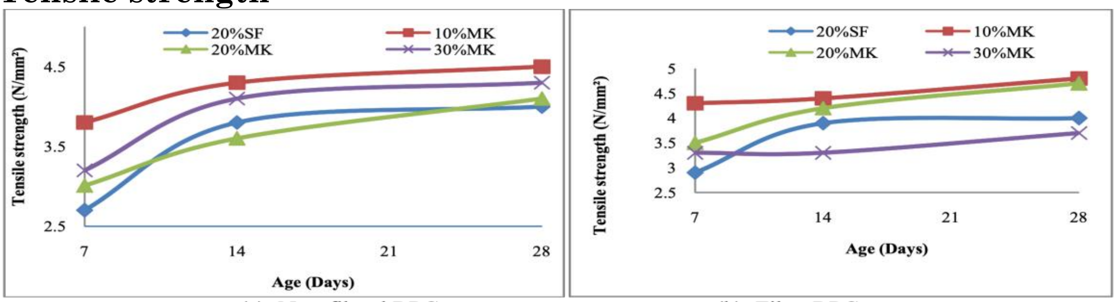
Figure 4: Effect of MK content on the compressive strength of RPC

Figures 4 (a & b) shows the effect of MK content on the compressive strength of non-fibred and fibre RPC at different ages. For the fibre and non-fibre specimens, increase in compressive strength with age can be observed. At 7 and 28 days, the compressive strengths of non-fibred specimen (Figure 4a) with 20% MK were comparable to those of the reference (20%SF). However, the specimen with 30% MK showed higher strength at 7 days but lower at 28 days. The improved strength exhibited by the 30%MK could be due to the fast pozzolanic reaction of MK at the early age due to the presence of more SiO2 that reacted with the Ca(OH)2 liberated during hydration to produce additional cementitious compounds such as C-S-H and CSAH.. On the other hand, the control concrete has higher early compressive strength compare to 10%MK due to high pozzolanic activity and finer particle sizes of the SF than the MK. At 28 days, the compressive strengths of specimens with 10%MK, 20%MK and 30%MK reduces by 10.9%, 2.9% and 8.7% respectively compared to the control (64.5 N/mm2). Hence, 20% seems to be the optimum content of MK to produce RPC with comparable compressive strength to that of the control.

However, the fibre specimens (Figure 4b) showed variation in compressive strength compared to the non-fibre one. At 7 days, the compressive strengths of the fibre specimens with 20%SF, 10%MK, 20%MK and 30%MK are 38.9N/mm2, 37.4 N/mm2, 38.8 N/mm2 and 29.9 N/mm2 respectively. While at 28 days, the compressive strengths of the specimens with 10%MK, 20%MK and

30%MK reduces by 11.4%, 4.7% and 31.4% compared to the control (50.3N/mm2). Apparently, the introduction of fibre led to reduction in strength probably due to the slippery surface of the GIW that could hinder adequate bond between the fibres and cement paste. This is supported by Iqbal, Ali, Holschemacher and Bier (2015) that state around 12% reduction in compressive strength with increase of steel fibre content from 0% to 1.25%. The compressive strength of RPC produced with 20%MK in this study is superior to those reported by Asteray, Oyawa and Shitote (2017) and Demiss, Oyawa and Shitote (2018) respectively.

Tensile strength



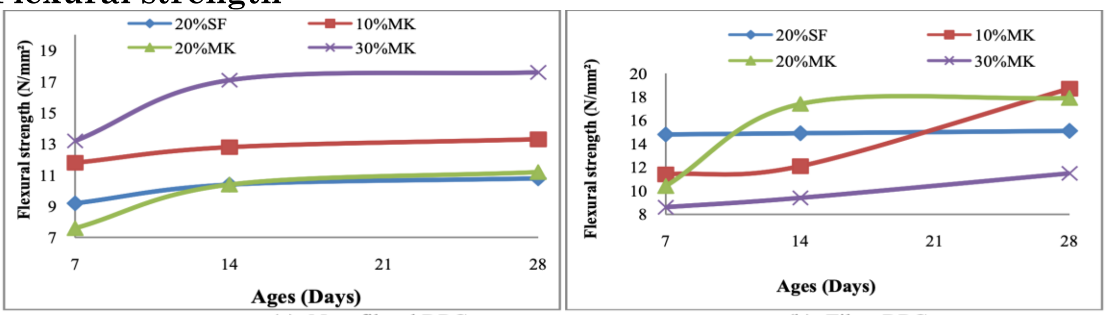
(a) Non-fibred RPC (b) Fibre RPC

Figure 5: Effect of MK content on the tensile strength of RPC

Figures 5 (a & b) depicts the split tensile strength of non-fibred and fibre RPC samples. As shown in Figure 4(a), the tensile strength of non-fibre specimens with MK at all ages were generally higher than that of the control. At 7 days, the tensile strength of the 20%SF, 10%MK, 20%MK and 30%MK were 2.7 N/mm2, 3.8 N/mm2, 3.01 N/mm2 and 3.2N/mm2 respectively. At 28 days, the tensile strengths for 10%MK, 20%MK and 30%MK were higher than that of the control by 29%, 10% and 16% respectively. The improvement in the tensile strength of the specimens with MK could be due to the pozzolanic effects of unrefined MK that enhance the microstructure of RPC (Shafiq, Nuruddin, Khan & Ayub 2015; Vipat & Kulkarni, 2016).

For the fibre specimens (Figure 5b), it is clear that the inclusion of fibre improve the tensile strengths of all the specimens. The strength improvement reduces with the increasing MK content at all ages. The tensile strengths of the specimens with 20%SF, 10%MK, 20%MK and 30%MK at 7 days are 2.9 N/mm2, 4.3 N/mm2, 3.5 N/mm2 and 3.3N/mm2 while those at 28 days are 4 N/mm2, 4.8 N/mm2, 4.7 N/mm2 and 3.7N/mm2 respectively. Hence, up to 30% MK can be used to develop fibred RPC with improved tensile strength.

Flexural strength



(a) Non-fibred RPC (b) Fibre RPC

Figure 6: Effect of MK content on the flexural strength of RPC

The flexural strengths of fibre and non-fibre RPC are presented in Figure 6 (a & b). Compared to the control (Figure 6a), MK improved the flexural strength of un-fibre RPC and the improvement goes along with the increase in MK content. At 28 days, the range of flexural strength of the MK based RPC is 11.23- 17.6 N/mm2. However, the flexural strength of the control is 11.2 N/mm2. Figure 6(b) shows that GIW fibre improved the flexural strengths of all the specimens. The extent of improvement over curing ages is more pronounced with the specimens made with MK but low with SF. Overall, 20% MK outperformed the other specimens at all ages. Hence, the 20% is the optimum MK content for flexural strength enhancement. The improvement in the flexural strength of the MK RPC could be due to the presence of GIW, micro filling effect and pozzolanic reaction of MK (Vipat & Kulkarni, 2016). Results similar to this study was also reported by Haroon, Ashad, Vikas and Alvin (2017) and Demiss, Oyawa and Shitote (2018).

X-Ray Diffraction (XRD) analysis

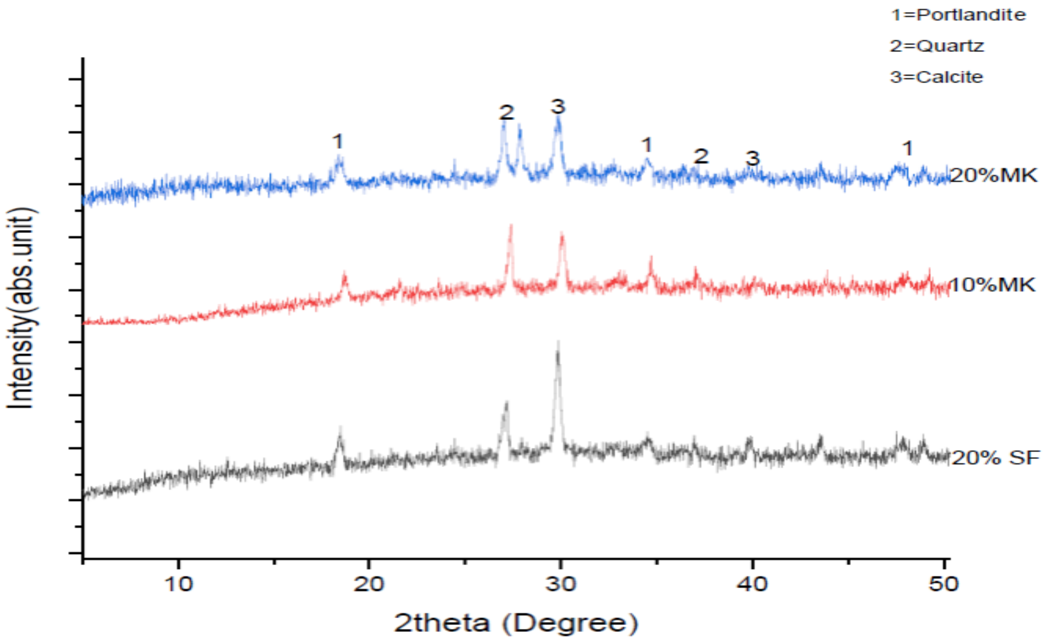


Figure 7: XRD patterns of RPC specimens

Figure 7 shows the XRD patterns of RPC specimens at 27oC. The crystalline phases present in the RPC are Ca(OH)2 (Portlandite) at 2θ=18.5o, quartz (at 2θ=27.5o) and calcite (at 2θ=30o). The diffraction peak of interest is that of Portlandite as its reduction is considered to contribute to strength and durability properties. It can be observed from Figure 7 that 20%MK have reduced diffraction peaks (Portlandite) than the 20%SF while 10%MK has lower peak than 20%SF. The reason for the higher peak of 20%SF than that of 20%MK could be due to agglomeration effect of silica fume at a percentage higher than 10% which prevented proper dispersion that can lead to the presence of un-reacted Ca(OH)2. This effect of the SF has been reported by Mitchell, Hinczak and Day (1998) and Zhang, Zhang and Yan (2016).

Scanning Electron Microscopy (SEM) analysis

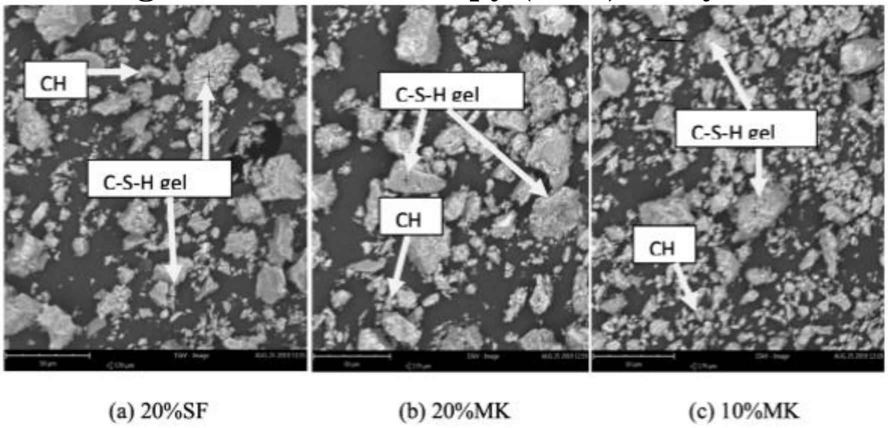


Figure 8: Scanning electronic microscopy (SEM) of RPC specimens

Figure 8(a, b & c) shows the SEM images of RPC specimens at ambient temperature. The image shows that crystalline CSH and crystal of CH are visible in the microstructure but more pronounced in 20%SF (a) and 20%MK (b). This confirms the higher strength recorded by 20%SF and 20%MK RPC specimens.

CONCLUSIONS

Unrefined metakaolin (MK) and gear inner wires (GIW) have been found to be suitable in the production of reactive powder concrete (RPC). Unrefined MK performs in similar way or slightly better than silica fume in terms of compressive, tensile and flexural strengths. The GIW positively affect the tensile and flexural strengths of the RPC but negatively affect the compressive strength. Unrefined MK of up to 20% by the weight of cement and GIW of up to 0.25% could be used in the production of RPC with compressive, tensile and flexural strengths of up to 64.5N/mm2, 4.7 N/mm2 and 18.7 N/mm2 respectively. This result has been confirmed by the XRD and SEM outcomes. RPC of this type can easily be produced without necessarily the need for pressure and heat treatment. Moreover, the use of the unrefined MK and GIW can lead to production of cheaper and sustainable RPC by cutting down importation cost of both SF and fibre materials.

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