LAUTECH Journal of Civil and Environmental Studies
Volume 3, Issue 1; September 2019

Appraisal of Indigenous Materials for Use in the Production of Ultra High Performance Fibre Reinforced Concrete

[1]Ibrahim, A. A., [2]Oyejobi D. O. and [3]Adedeji A. A.
[1,2,3]Department of Civil Engineering, University of Ilorin, ilorin, Kwara State, Nigeria.
Corresponding E-mail: ibrahim.abdullahi39@gmail.com

Abstract

It is important to advance the technology of concrete due to incidences of structural failure, terrorist attack and natural disaster which has led to the evolution of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) as a means to develop novel materials to build structures with superb strength, high ductility and repairing structures that have experienced structural failure. Development of agro-industrial waste materials for production of UHPFRC will significantly reduce the energy consumed and the environmental impacts during concrete production. In this study, a literature review of the production, properties and usage of UHPFRC was conducted. Following the review, locally available materials that could be used to replace the important constituent materials of UHPFRC were appraised. It was gathered that UHPFRC is an excellent strengthening material with ultra-high mechanical properties for structural applications. The major components of UHPFRC are cement, silica fume, steel fibre, water, superplasticizer, and sand. Recycled steel fibre and rice husk ash (RHA) are locally available materials and have similar properties to industrial steel fibre and silica fume respectively. These local materials can be incorporated into concrete to further improve the properties of concrete, promote sustainability and discourage importation of silica fume and different types of fibres.

Keywords: Recycled steel fibre, Rice Husk Ash, Silica fume, Steel fibre, UHPFRC

Introduction

Concrete is a building material formed by a mixture of fine aggregate, coarse aggregate, water, cement which bond together and hardens over time. Concrete is one of the most commonly used artificially made materials in the world and it is used to build infrastructures such as schools, hospitals, bridges, roads, and more. The future of concrete focuses on the use of nanomaterial, sustainability, durability, energy efficiency and strength which gave rise to the evolution of Ultra High-Performance Fibre Reinforced Concrete (UHPFRC). UHPFRC is a novel cementitious material with fibres embedded within it, which help UHPFRC overcome its brittleness. Depending on the ingredient composition and the manufacture procedure, the compressive strength of UHPFRC typically ranges from 150 N/mm^2 to 800 N/mm^2 (Huang, Kazemi-Kamyab, Sun, & Scrivener, 2017), and it has exceptional high energy absorption prior to fracture (Wille, El-Tawil, & Naaman, 2014).

The global demand for infrastructure investment is huge, and existing infrastructures are fast wearing out. It is important for engineers to adopt novel material like UHPFRC because of its proven ultra-high properties in flexure (Safdar, 2016), tensile (Pyo, El-Tawil, & Naaman, 2016), compressive (Rabehi, Ghernouti, Li, & Boumchedda, 2014), sustainability (Larsen, Aasbakken, O'Born, Vertes, & Thorstensen, 2017), blast resistance (Yoo & Banthia, 2017), and crack mitigation (Kim, Park, Jang, Feo, & Yun, 2015), for development of new structures and rehabilitation of the existing infrastructures to making them more effective, economical and durable. Experimental and numerical studies have been conducted by researchers to prove relevance of UHPFRC in the construction industry. However, more studies are needed to figure out how locally sourced materials can be used to produce UHPFRC in order to make it affordable and enhance its sustainability.

Rice production in Nigeria as at 2017 has reached 15 million metric tonnes annually, up to 34 states in Nigeria are currently producing rice, with many states producing 3 times a year (Ahmad, 2017). Silicon dioxide can be found in Rice Husk Ash (RHA), which is a residue of rice husk. The high cement content with the Silica fume-to-cement ratio of 0.25 leads to a high amount of Silica Fume (SF), in UHPFRC mixtures. However, this also causes disadvantages in developing countries where there are limited resources and significant cost constraints. This provides the motivation for researching other materials with similar performances to be used instead of SF (Tuan, Ye, Breugel, & Copuroglu, 2011).

In 2013, the worldwide production of the tyre is estimated to be about 1.5 billion each year and this will eventually turn out to be used tyres and constitute waste materials (Williams, 2013). Nigeria with the largest population in Africa which was estimated at 190.9 million people in 2017 (Trading Economics, 2019), produces a substantial quantity of used tyres and these used tyres constitute a menace to the society with serious environmental problems (Akindahunsi, Oladimeji, & Ilaboya, 2016). To attain economically viable and environmentally friendly tyre recycling, it is necessary to develop new applications and products, which will use tyre by-products as raw materials (Pilakoutas, Neocleous, & Tlemat, 2004). In particular, the incorporation of recycled steel fibre recovered from waste tyres in normal strength concrete has been widely explored. The Recycled Steel Fibres (RSF) effectively improved the behaviour of normal strength concrete after the peak-load was reached and that RSF is similar to the industrial steel fibre in enhancing the energy absorption, pull-out behaviour and post-cracking behaviour of normal concrete (Aiello, Leuzzi, Centonze, & Maffezzoli, 2009).

Ultra High Performance Fibre Reinforced Concrete

Protective design in structural engineering has become more prevalent over the last few decades which led to the invention of UHPFRC. It is a composite material, comprised of a relatively large proportion of steel fibres, low water-binder ratio and high micro silica content (Brühwiler, Denarié, & Habel, 2005). Thus, making UHPFRC a composite with superior characteristics such as self-consolidating, very high strength, high modulus of elasticity and extremely low permeability that prevents the ingress of detrimental substances such as water and chloride ions (Brühwiler et al., 2005). UHPFRC is characterised by the high ratio (up to 10%) of steel fibres of diameter 0.15–0.20 mm, and high tensile strength in the range of 859–2000 N/mm^2. UHPFRC often has a cement content as high as 900–1000 kg/m^3, very fine sand or quartz powder and silica fume are also essential to achieve high particle packing density (Hassan, Jones, & Mahmud, 2012). This composition leads to very high compressive strength and tensile strength, typically over 150 N/mm^2 and 7 N/mm^2 respectively (Hassan et al., 2012). An example of a bridge constructed with UHPFRC is shown in Figure 1.

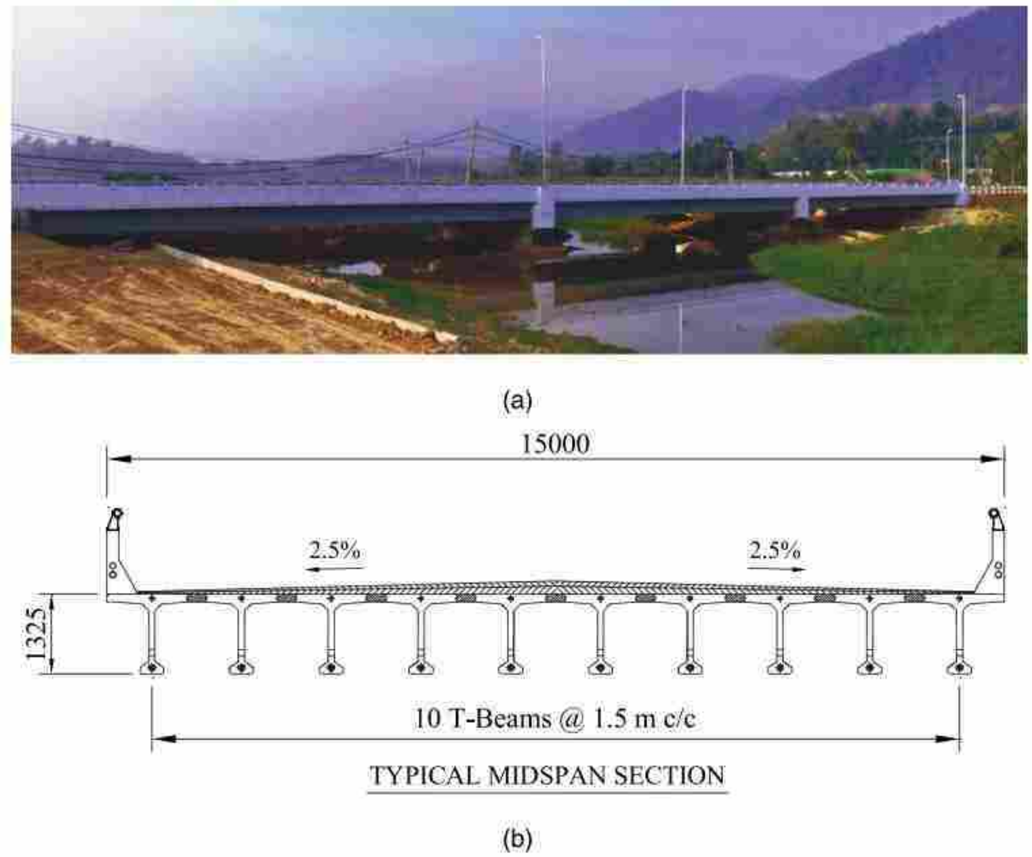

Figure 1: (a) Sungai Nerok bridge (b) Typical Section View (Voo, Foster, & Voo, 2014).

Constituent Materials of Ultra High Performance Fibre Reinforced Concrete

Silica Fume - SF is a by-product of producing ferrosilicon alloys. SF comprises primarily amorphous silica which always surpasses 85% and contributes to the distinctive strength and durability of UHPFRC. SF has a bulk density of about 200–300 kg/m^3. With worries over silicosis, SF is provided to the concrete industry in slurry form, with a specific gravity of around 1400 kg/m^3. The use of a slurry enables better dispersion of the silica fume within the concrete mix, leading to a more homogeneous material and better quality control (Black, 2016).

Fibre Reinforcement – According to (Hassan et al., 2012), (Yin, Teo, & Shirai, 2017), and (Wang, Gao, Li, & Yang, 2018) steel fibre is the most commonly explored fibre in UHPFRC, it contributes toward increase of flexural tensile strength (Kang, Lee, Park, & Kim, 2010) and enhances toughness of UHPFRC (Kang & Kim, 2011). Steel fibre could also limit shrinkage and increases the compressive strength of concrete in early ages (Tanarslan, 2017).

Superplasticizers – According to (Kang et al., 2010), (Sudarshan & Rao, 2017), (Tayeh, Abu Bakar, Johari, & Voo, 2013), Polycarboxylate superplasticizer is the most commonly used superplasticizer in the production of UHPFRC. Polycarboxylate superplasticizer helps in increasing the workability of concrete without the addition of surplus water. These molecules physically separate the cement particles by opposing their attractive forces with steric and/or electrostatic forces (Gelardi & Flatt, 2016). As a result, the concrete is easier to place.

Cement - Cement is gotten from the calcination of limestone, iron ore, and clay at 1,450°C. The product of the calcination process is clinker, which is finely ground with gypsum and other chemical additives to produce cement (CEMEX, 2019). Ordinary Portland cement is the most commonly used type of cement in the production of UHPFRC (Sudarshan & Rao, 2017), (Rong, Sun, & Zhang, 2010), (B. Wang, Xu, & Liu, 2016). Portland cement improves the bond strength of UHPFRC (B. Wang et al., 2016).

Water - Water reacts chemically with cement and causes the heat of hydration. The water to be used must be clean, neat, free from impurities and should be in accordance with BS EN 1008. Water leads to stronger formations of silicate hydrates when curing UHPFRC in its early stages in room temperature (Joe, Moustafa, & Ryan, 2017). Water also plays an active role in the workability of UHPFRC.

Sand - In the production of UHPFRC, natural river sand free from impurities with a particle size distribution between less than 0.5 mm (Kang et al., 2010) and 2.5 mm (Rong et al., 2010) can be used as fine aggregate. However, quartz sand (or silica sand) is more suitable for this kind of production as a result of its richness in silicon dioxide (Sudarshan & Rao, 2017). AL Hallaq, Tayeh, and Shihada (2017); Prem, Murthy, Ramesh, Bharatkumar, and Iyer (2015) and Tanarslan (2017) reported that the very fine quartz sand has particle size between 0.1-10 µm, larger particles of quartz sand have particle sizes ranging 10-150 µm (AL Hallaq et al., 2017), while Sudarshan and Rao (2017) reported the particle sizes to be between 150–1000 µm. The quartz sand also serves as filler material used for UHPFRC (Tanarslan, 2017); (Yang, Joh, & Kim, 2011) and contribute positively towards the development of strength in UHPFRC. Sand helps in the adjustment of the strength of UHPFRC by variation of its proportion with cement. Sudarshan and Rao (2017), Tanarslan (2017), Rong et al. (2010) and Wang et al. (2018) among others have explored blending of quartz sand and natural river sand in the production of UHPFRC and it has yielded a significant result.

Mix proportions of ultra high performance fibre reinforced concrete

Different material mix designs have been used by different researchers for the production of UHPFRC. UHPFRC mix designs and in turn, mechanical properties can vary significantly based on many different factors such as admixtures, and steel fibres ratio. Table 1 shows the various mix designs and their compressive strengths as compiled from different researchers. The respective compressive strengths of the various mix designs are represented in a bar chart in Figure 2.

Table 1: Mix Proportions of Ultra High Performance Fibre Reinforced Concrete

Source	Portland Cement (kg/m^3)	Silica Fume (kg/m^3)	Steel Fibre (kg/m^3)	Super-plasticizer (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Sudarshan and Rao (2017)	800	200	168	28	240	144
Tanarslan (2017)	1000	250	215	25	758	200
Kusumawardaningsih, Fehling, and Ismail (2015)	795	168	160	24	1169	181
Nicolaides, Kanellopoulos, Savva, and Petrou (2015)	880	220	481	67	833	172
Rabehi et al. (2014)	800	200	194	53	1144	200
Habert, Denarié, Šajna, and Rossi (2013)	1434	373	707	47	80	189
Hassan et al. (2012)	657	119	157	40	1051	185
Hakeem (2011)	900	220	157	40	1005	162

Rong et al. (2010)	400	100	312	20	1200	150
Graybeal (2007)	710	230	156	31	1020	110

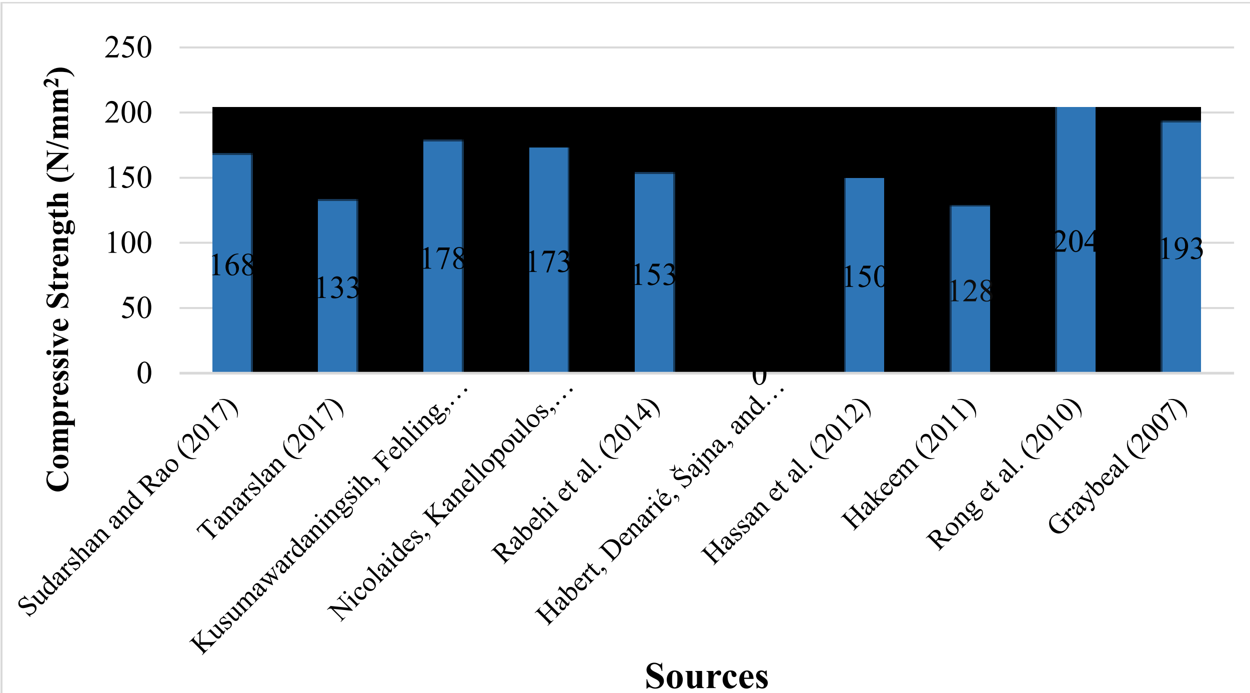

Figure 2: Compressive strength of the respective mix designs of Ultra high performance fibre reinforced concrete.

The average compressive strength produced by the various mix designs is 164 N/mm2, which meets the high strength characteristic of UHPFRC. Moreover, it was observed that the mix design used by Rong et al. (2010) produced 204 N/mm^2, the highest compressive strength. It is also the most effective mix design comparative to other mix designs by the aforementioned researchers. Conversely, the mix design utilized by Hakeem (2011) produced the least compressive strength of 128 N/mm^2.

Mechanical properties of ultra high performance fibre reinforced concrete:
Flexural characteristics of ultra high performance fibre reinforced concrete

The flexural strength of a conventional reinforced concrete member can be increased via application of UHPFRC. Tanarslan (2017) posits that UHFRPC laminate for strengthening is a reliable technique for flexural strengthening and it increases the performance of every RC specimen to which UHFRPC laminate was applied. In the same vein, Prem et al. (2015) reported that RC beams can be successfully retrofitted with UHPFRC using adhesive bonding of precast material. Tayeh, Abu Bakar, Johari, and Zeyad (2013) asserts that adhesion bond strength between NC substrate and UHPFC was stronger than the substrate irrespective of the substrate surface roughness. Similarly, Tanarslan (2017) explained that gluing or anchorage usage for flexural strengthening is effective to increase the stiffness of specimens. The ultimate strength and stiffness of reinforced concrete beams, which were repaired in the tension zone, were increased with the increase of UHPFRC thickness (Safdar, 2016). On the contrary, Paschalis and Lampropoulos (2015) reported that there was an increment of the flexural strength values of UHPFRC beams as the depth was reduced. Beams with depth in the range of 25 mm to 100 mm were found to be between 31.2 N/mm^2 and 20.1 N/mm^2 (Paschalis & Lampropoulos, 2015). Both authors (Safdar (2016) and Paschalis and Lampropoulos (2015)) showed that the flexural strength of UHPFRC beam is affected by the thickness of the beam. Al-Osta, Isa, Baluch, and Rahman (2017) posited that the flexural strength of strengthened RC beams increases with the increasing percentage volume of steel fibres in UHPFRC. A minimum increase of 32% and a maximum of 208% at load carrying capacity was obtained from the UHPFRC strengthened specimens (Tanarslan, 2017).

Crack damage mitigation ability of ultra high performance fibre reinforced concrete

UHPFRC experience early age shrinkage crack for the reason that it consumes a lot of cement in the course of its production, which eventually results in it undergoing high exothermic hydration reaction. However, UHPFRC is able to mitigate crack due to its unique strain-hardening response and superb bond strength (Yoo, Banthia, & Yoon, 2016). Gergely and Lutz (1968) and Shihada and Oida (2013) recommended the use of UHPFRC for the repair of beams damaged in the form of excessive cracking because beams repaired using UHPFRC shows fewer crack widths and lengths compared to the beams repaired using normal concrete. Yoo, Min, Lee, and Yoon (2014) recorded maximum crack width of 0.3 mm after 9 days and the net free shrinkage strain was found to be -689 με to -723 με at 9 days by subjecting UHPFRC slabs to stress concentration at the centres of the slabs. Similarly, Yoo et al. (2016) reported that the 30-day shrinkage strain of specimen with 0 % Shrinkage Reducing Admixture (SRA) at a depth of 13 mm was found to be −862 με, approximately 5% and 12% higher than those of specimens with 1 % SRA and 2 % SRA, respectively. The author concluded that the use of thicker UHPFRC slabs was effective in decreasing the degree of restraint and increasing the shrinkage crack resistance compared to those of thinner slabs. Yoo and Banthia (2017) reported that shrinkage crack occurs very early for a thinner UHPFRC specimen of 35 mm, whereas no shrinkage crack was obtained in a thicker specimen 45 mm during testing. In another report, Yoo et al. (2014) asserted that the slabs with the lowest thickness of 40 mm exhibited shrinkage cracks, whereas the slabs with higher thicknesses of 60 and 80 mm showed no shrinkage cracks during testing.

Application of ultra high performance fibre reinforced concrete for the rehabilitation of the deteriorated structure.

Reconstruction of deteriorated concrete structures leads to significant user costs. Hence, it is crucial to develop novel concepts for the strengthening of concrete structures. Martín-Sanz, Chatzi, and Brühwiler (2016) reported that promising is the applicability of UHPFRC at increased slopes, delivering satisfactory results which permits rehabilitation of surfaces that are not easily accessible by other means. Lampropoulos, Paschalis, Tsioulou, and Dritsos (2016) observed superior performance for beams strengthened with UHPFRC three side jackets, and the shrinkage strain was 30% reduced in case of UHPFRC with 3% steel fibres, compared to the respective measurements of plain UHPFRC. Denarié and Brühwiler (2006) proposed UHPFRC as a means to simplify the construction process, increase the durability of structures and their mechanical performance (stiffness and resistance), and decrease the number of interventions during their service life.

Improvement of concrete environmental impact by using ultra high performance fibre reinforced concrete.

Researchers have conducted a comparative study to investigate the performance of road bridges using conventional concrete and UHPFRC. Road bridges constructed with UHPFRC solution consumed 37% less material, 20% less embodied energy, and 24% less CO_2 emissions and provides for Global Warming Potential (GWP) reduction of 18% over that of the conventional solution (Voo et al., 2014). Similarly, Bizjak, Šajna, Slanc, and Knez (2016) asserted that the GWP resulting from the strengthening renewal works using UHPFRC deck is lower by 76% relative to that for the concrete bridge construction. The result is in correlation with the Life Cycle Assessment for the Sherbrooke Footbridge and the Gärtnerplatz Footbridge (Stengel & Schießl, 2009) wherein the calculated reduction was approximately 60–85% in comparison with normal concrete. In the same vein, Dong (2018) reported that by using UHPFRC, the volume of the concrete can be reduced by 48%, the uses of rebar and prestressing steel are reduced by 39% and 44%, respectively. Thus, the UHPFRC results in 51.3% reduction of the total weight of the superstructure. Dong (2018) and Voo et al. (2014) concluded that the reduced weight of UHPFRC superstructure can lead to a considerably reduced size of the substructure. On the contrary, Stengel and Schießl (2009) concluded that even with reduced cross-sectional areas due to UHPFRC's high load-bearing capacity, many other components are energy-intensive and are increased to guarantee its unique mechanical properties. Figures 3 and 4 show the result of the research conducted by (Stengel & Schießl, 2009). The results show that UHPFRC in the Sherbrooke Pedestrian Bridge contribute about 60 – 85% of the environmental impact and 44 – 74% for the Mars Hill Bridge. Accordingly, Stengel and Schießl (2009) recommended that the use of cement, superplasticizers, and steel fibres be kept to a minimum to reduce its environmental impact.

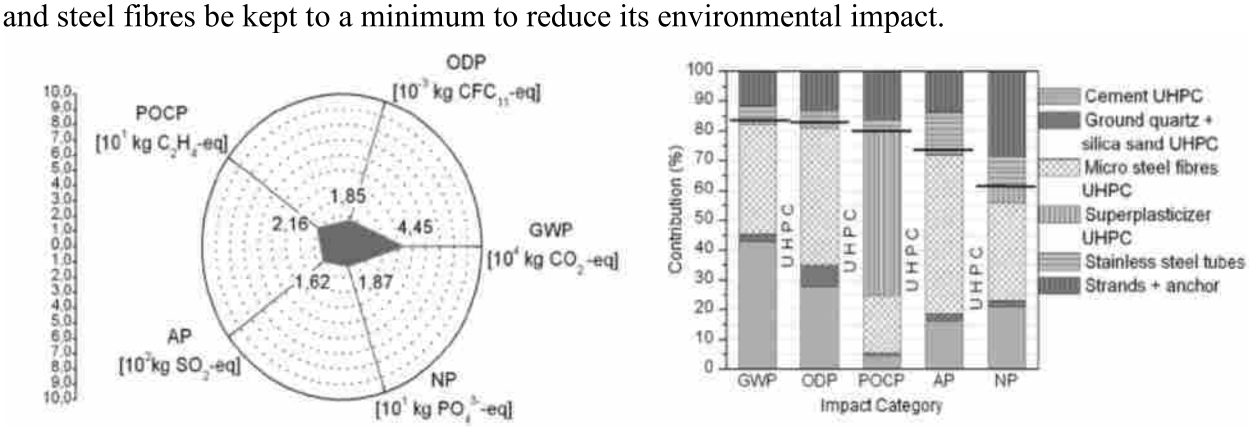

Figure 3: (a) Environmental impact assessment of the production and (b) the percentage contribution of each material used in the Sherbrooke Pedestrian Bridge (Stengel et al., 2009).

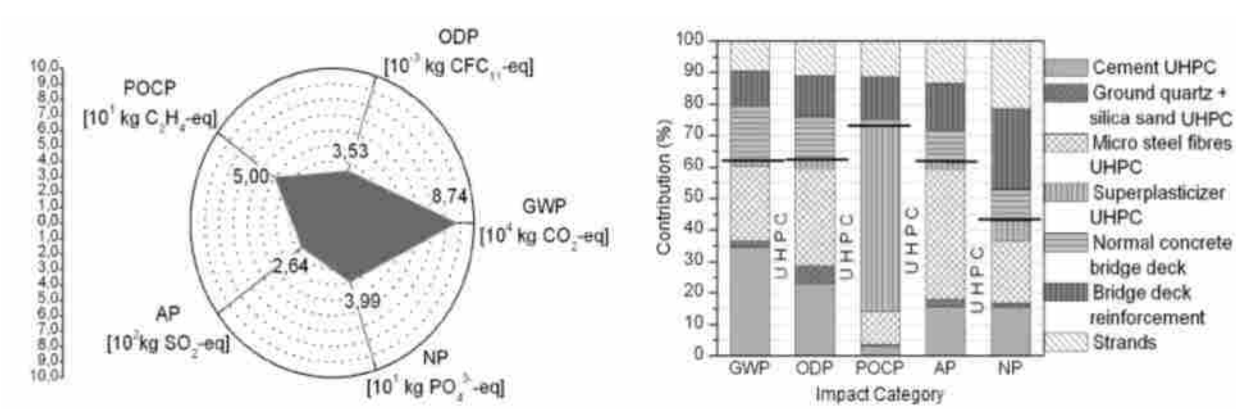

Figure 4: (a) Environmental impact assessment of the production and (b) the percentage contribution of each material used in the Mars Hill Bridge (Stengel et al., 2009).

Improvement of concrete compressive strength by using ultra high performance fibre reinforced concrete.

It is advantageous to rehabilitate structural members rather than demolishing and reconstructing them. The process of increasing the section of a damaged structural member with UHPFRC application, as a method of rehabilitation can significantly increase the ultimate load and axial strain of the damaged concrete. Moreover, with a gain in compressive strength and axial strain of about 58 and 50%, respectively, comparatively with specimens not damaged (Rabehi et al., 2014). Figure 5 shows the effect of fibre content, curing ages on compressive strength. It can be deduced that there is a 32.2 N/mm^2 strength gain when curing age increases from 28 days to 90 days, while only 9.9 N/mm^2 gain from 90 days to 180 days. Hence, from the view of time and energy, saving 90 days of curing ages is enough to achieve most of the ultimate strength. In addition, the compressive strength increase with the increase in fibre content (Rong et al., 2010). Similarly, Graybeal (2007) observed that the curing procedure affect the strength of UHPFRC concrete.

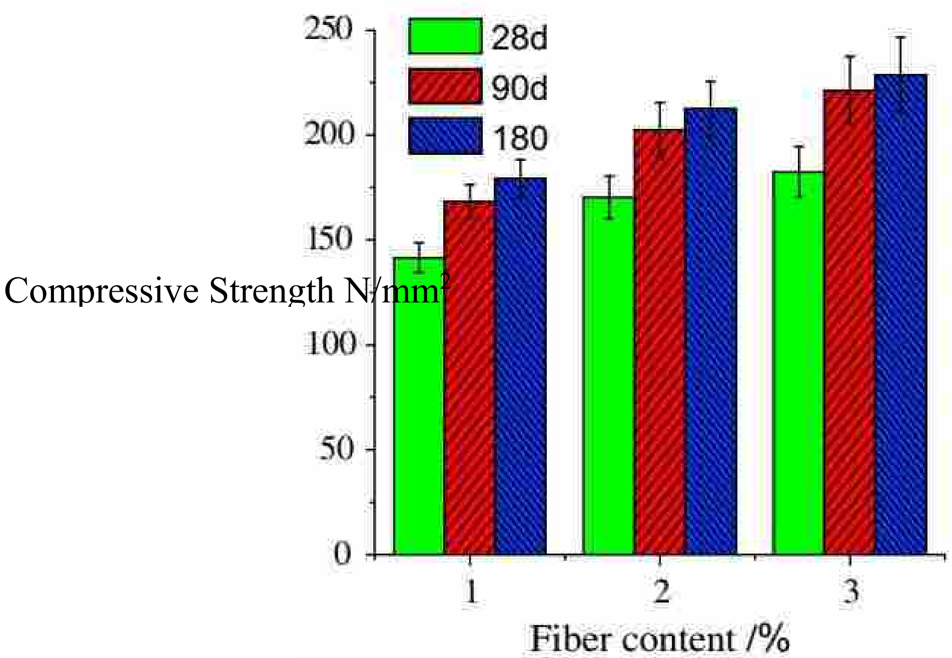

Figure 5: Effect of fibre content, curing ages on compressive strength (Rong et al., 2010)

Possible application of local materials for the production of ultra high performance of fibre reinforced concrete.

Rice Husk Ash (RHA)

Rice husk ash (RHA) is the solid residue after burning rice husks (RH), an agricultural waste widely produced all over the world (Pode, 2016). The ash obtained after complete combustion of the husk in controlled conditions contains 90–96% silica in an amorphous form, the ash was found to be highly pozzolanic and therefore an excellent supplementary cementing material (Mehta, 1992). The X-ray diffraction (XRD) analysis shown in Figure 6 indicates that both SF and RHA contain mainly amorphous silicon dioxide, this indicates that RHA could serve as a good replacement for SF in development of UHPFRC.

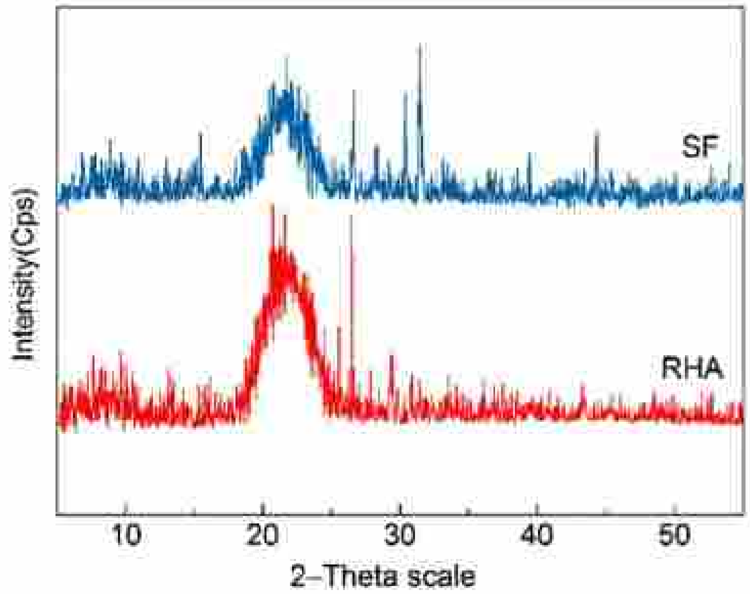

Figure 6: X-ray Diffraction Patterns of RHA and SF (Huang, Gao, Wang, & Ye, 2017).

Physical properties of rice husk ash

Researchers such as Foong, Alengaram, Jumaat, and Mo (2015) and Noorvand, Ali, Demirboga, Farzadnia, and Noorvand (2013) reported a black colour while Bakar, Putrajaya, and Abdulaziz (2010) and Aprianti, Shafigh, Bahri, and Farahani (2015) reported RHA to be grey in colour (Figure 7). The difference in observed colour could be the result of the different burning condition. Specific gravity result from all reviewed articles is in the range of 1.94-3.68. (Karim, Zain, Jamil, & Lai, 2013) recorded a specific surface area of 1.27 m^2/g, (Jamil, Khan, Karim, Kaish, & Zain, 2016) recorded 1.67 m^2/g while (Givi, Rashid, Aziz, & Salleh, 2010) recorded 2.44 m^2/g. Basha, Hashim, Mahmud, and Muntohar (2005), Foong et al. (2015) and Rahman, Muntohar, Pakrashi, Nagaratnam, and Sujan (2014) stated that RHA has an average particle size of 45 µm, 20 µm and 75 µm respectively. This level of fineness will affect the reactivity of the binder with aggregates and strength development as well. Also, Ling and Teo (2011) and Basha et al. (2005) reported water absorption of RHA to be 14% and 26% respectively.

Figure 7: (a) Raw rice husk (b) Rice Hush Ash (RHA) (Aprianti et al., 2015).

Chemical properties of rice husk ash

The chemical composition of Rice husk ash from different authors is shown in Table 2. It can be perceived that RHA is very rich in silica content, generally above 80% but low in Calcium, Alumina and Iron oxides and this will affect certain concrete properties and in other to make a remedy for such, RHA can be used with other pozzolanic materials that are rich in these oxides. Similar to SF, the RHA is considered as ‘‘highly active pozzolans’’ (Mehta, 1992).

Table 2: Chemical Composition of Rice Husk Ash

Sources	Oxide composition in (%)										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	MnO	TiO_2
Mohseni, Khotbehsara, Naseri, Monazami, and Sarker (2016)	91.15	0.41	0.21	0.41	0.45	0.62	0.05	6.25	-	-	-
Foong et al. (2015)	93.46	0.58	0.52	1.03	0.51	-	0.08	1.82	-	-	-
Rahman et al. (2014)	94.8	-	1.61	1.41	-	-	-	1.33	-	0.28	0.17
Noorvand et al. (2013)	89.6	-	0.75	1.5	-	0.67	-	7.05	-	0.32	-
Karim et al. (2013)	87.75	0.38	0.19	1.04	0.69	0.56	0.05	2.83	1.31	0.07	0.02
Ling and Teo (2011)	87.97	0.2	0.46	0.54	0.36	0.13	0.03	2.16	0.9	0.16	0.03
Chik, Jaya, Bakar, and Johari (2011)	90.0	0.39	0.37	0.46	0.88	-	0.07	3.1	1.6	0.04	-
Givi et al. (2010)	87.86	0.68	0.68	-	0.58	-	0.38	0.21	0.2	0.4	0.41

In 2011, Nguyen (2011) found that the rice husk ash (RHA) can be used as effective internal curing agents for UHPFRC. The main advantages of using RHA are the decrease in materials costs due to cement savings, environmental benefits related to the disposal of waste materials and the reduction of carbon dioxide emissions. Moreover, RHA has pozzolanic properties, which can be treated as silica fume replacement with benefits to the environments (Nguyen, 2011). Compared to SF, the fineness of RHA has a favourable effect on compressive strength when cured in the normal condition (Van Tuan, Ye, Van Breugel, Fraaij, & Dai Bui, 2011). Hence, RHA is suitable for use as supplementary material to make UHPFRC.

Waste tyre steel fibre

According to Leade (2019), Steel fibre is a special cement concrete reinforcing and toughening composite stiffened structure. According to the manufacturing process, it can be divided into: high strength cold drawn steel wire steel fibre, cutting steel fibre, milling steel fibre, molten steel fibre pumping. In addition, according to the material, it can be divided into: carbon steel fibre, stainless steel fibre, aluminium metal fibre, copper fibre, titanium alloy fibre, among other types of steel fibre. These steel fibres usually have their tensile strength ranging between 300 and 2500 N/mm^2. However, copper-plated steel fibre has its tensile strength greater than 2850 N/mm^2 (Leade, 2019).

Waste tyre steel fibre is a recently developed Recycled Steel Fibre (RSF) from post-consumer tyres. Tyre shredding and the cryogenic process can be used to mechanically recover RSF from used tyres. In addition, steel fibres can be recovered by utilising anaerobic thermal degradation, such as conventional pyrolysis and microwave-induced pyrolysis of tyres (AMAT, 2003). Tyres of light vehicles contain up to 15% steel, whereas truck tyres contain up to 25% steel (Hylands & Shulman, 2003).

Properties of waste tyre steel fibre

In 2009, Aiello et al. (2009) examined steel fibres recovered by shredding process of waste tyres. The fibre diameters varied between 0.17 and 2.00 mm. The average fibre length was 26 mm. Mechanical properties of steel fibres were evaluated by tensile tests on three classes of fibres with average diameters of 0.36, 0.30 and 0.25 mm, in order to compare RSF to industrial steel fibres and the result is shown in Table 3.

Table 3: Tensile Strength of the Recycle Steel Fibres (Aiello et al., 2009)

Diameter (mm)	Tensile strength (N/mm^2)
0.36	2239
0.30	2578
0.25	2314

In an experimental investigation by Akindahunsi et al. (2016), the result of the average ultimate tensile strength of a strand of RSF having 1 mm diameter tested was 280.3 N/mm^2 while steel bar having 10 mm diameter gave 373 N/mm^2. The results obtained for steel fibre reinforced concrete and steel reinforced concrete beams cured in portable water after 91 days were 17.34 N/mm^2, 15.24 N/mm^2 respectively. And for steel fibres and steel reinforcements beams cured in 23 g/l chloride environment after 91 days the flexural strengths were 15.7 N/mm^2 and 14.6 N/mm^2 respectively. While the flexural strengths of steel fibres and steel reinforcements beams cured in 31 g/l chloride environment after 91 days were 14.7 N/mm^2 and 12.8 N/mm^2 respectively. The results of the flexural tests carried out on concrete beams indicated that RSF gave a better flexural performance than steel reinforcement. The large difference in the RSF tensile strength obtained by Akindahunsi et al. (2016) and Aiello et al. (2009) is as a result of the difference in the waste tyres been recycled.

In another research, Rossli and Ibrahim (2012) studied the concrete properties with 0% to 1% at intervals of 0.2% volume fraction of tire fibres. All of the recorded results achieved the concrete strength design required except for 0.6%, it managed to achieve 34.50 MPa whereas the required strength is for concrete Grade 40. Rossli and Ibrahim (2012) and Aiello et al. (2009) posited that RSF specimens are comparable to ISF specimens in terms of its contribution to compressive strength, flexural strength and pull-out behaviour of concrete. The use of RSF in concrete (like any other type of steel fibres) can eliminate the use of conventional reinforcement (Akindahunsi et al., 2016) and can increase the speed of construction (Pilakoutas et al., 2004). A recently filed patent (British Patent Application No. 0130852.7, University of Sheffield, December 24, 2001) claims that steel fibres recovered from used tyres RSF can be used as fibre reinforcement to enhance the flexural strength and ductility of concrete. RSF is efficient in restraining the propagation of micro-cracks into meso-cracks while industrial steel fibre is more efficient in holding macro-cracks together (Graeff, Pilakoutas, Neocleous, & Peres, 2012). Hence, a combination of both recycled and industrially produced fibres will be ideal in increasing the fatigue endurance life of UHPFRC.

Proposed Mix Design for the Indigenous Ultra High Performance Fibre Reinforced Concrete

A mix design which includes local materials for the production of UHPFRC is proposed with the aid of "Design Expert 7.0" software. The "Design expert" software produced three choices of result and the choice with the highest desirability value of 0.822 was chosen as the proposed mixed design for this study. The proposed mix design gave a compressive strength, flexural strength and tensile strength of 246.93 N/mm^2, 21.29 N/mm^2, 8.44 N/mm^2 respectively. The proposed UHPFRC mixture is shown in Table 4.

Table 4: Proposed Ultra High Performance Fibre Reinforced Concrete Mix Design

Components of UHPFRC	% Composition	Composition (kg/m^3)
Cement	26.5	725.6
Sand	42.8	1171
Water	7.6	208
Superplasticiser	4	109.5
Rice husk ash	12	328
Recycled steel fibre	7	191.7

Conclusion

The following conclusion can be drawn from the broad literature review:

i. Ultra High Performance Fibre Reinforced Concrete (UHPFRC) has been successfully applied in the construction industry and it has proven to be highly remarkable as a result of its high mechanical properties, economical and sustainable benefit and ductility among other properties.
ii. In terms of rehabilitation, UHPFRC has proven to improve the ability of a normal concrete to resist failure in bending by 208% or more; depending on the mix design of UHPFRC.
iii. UHPFRC mitigate crack due to its exceptional bond strength. Moreover, UHPFRC members with thickness greater than 60 mm do not demonstrate cracking
iv. UHPFRC impact on the environment is minimal, and cause reduction greater than 50% of the total weight of the structure where it is utilized as the major construction material compared to the normal concrete.
v. The compressive strength of UHPFRC increases not only with curing age but also with the percentage of fibre content added to it.
vi. Rice Husk Ash (RHA) contain amorphous silicon dioxide; hence, it would serve as a good replacement for Silica Fume in the production of UHPFRC. Moreover, RHA is a pozzolana; hence, it would significantly reduce the amount of cement utilized in the production of UHPFRC
vii. Steel fibres recovered from used tyres demonstrate exceptional tensile strength, about 2578 N/mm^2, and thus can be used to replace industrial steel fibres. Although, the strength of the recycled steel fibres depends on the kind of tyre being recycled.

Recommendation

The following are the recommendations from the study:

i. The use of UHPFRC for strengthening and repair of infrastructures that have experienced structural failure should be adopted over the construction of new structures.
ii. Extensive experimental studies should be conducted to show the ideal mix proportion required to produce a very high quality UHPFRC with local materials for different applications

References

Ahmad, M. (2017). Rice production in Nigeria hits 15 million tonnes, *Premium Times*. Retrieved April, 12, 2019 from https://www.premiumtimesng.com/agriculture/agric-news/240287-rice-production-nigeria-hits-15-million-tonnes-official.html

Aiello, M. A., Leuzzi, F., Centonze, G., & Maffezzoli, A. (2009). Use of steel fibres recovered from waste tyres as reinforcement in concrete: pull-out behaviour, compressive and flexural strength. *Waste management, 29*(6), 1960-1970.

Akindahunsi, A. A., Oladimeji, B., & Ilaboya, O. (2016). *An assessment of flexural strengths of concrete reinforced with steel fibre from used tyres.* Paper presented at the Valorisation of Industrial By-products for Sustainable Cement and Concrete Construction.

Al-Osta, M. A., Isa, M. N., Baluch, M. H., & Rahman, M. K. (2017). Flexural behavior of reinforced concrete beams strengthened with ultra-high performance fiber reinforced concrete. *Construction and Building Materials, 134*, 279-296.

AL Hallaq, A., Tayeh, B. A., & Shihada, S. (2017). Investigation of the Bond Strength Between Existing Concrete Substrate and UHPC as a Repair Material. *Investigation of the Bond Strength Between Existing Concrete Substrate and UHPC as a Repair Material, 6*(3).

AMAT. (2003). Advanced molecular agitation technology. Retrieved April, 12, 2019 from www.amat-ltd.com

Aprianti, E., Shafigh, P., Bahri, S., & Farahani, J. N. (2015). Supplementary cementitious materials origin from agricultural wastes–A review. *Construction and Building Materials, 74*, 176-187.

Bakar, B. H. A., Putrajaya, R., & Abdulaziz, H. (2010). Malaysian rice husk ash–improving the durability and corrosion resistance of concrete: pre-review. *Concrete Research Letters, 1*(1), 6-13.

Basha, E., Hashim, R., Mahmud, H., & Muntohar, A. (2005). Stabilization of residual soil with rice husk ash and cement. *Construction and Building Materials, 19*(6), 448-453.

Bizjak, K. F., Šajna, A., Slanc, K., & Knez, F. (2016). Environmental life cycle assessment of railway bridge materials using UHPFRC. *Materials and Geoenvironment, 63*(4), 183-198.

Black, L. (2016). Low clinker cement as a sustainable construction material *Sustainability of Construction Materials* (pp. 415-457). University of Leeds, Leeds, United Kingdom: Woodhead Publishing Series in Civil and Structural Engineering.

Brühwiler, E., Denarié, E., & Habel, K. (2005). *Ultra-high performance fibre reinforced concrete for advanced rehabilitation of bridges.* Paper presented at the Proc. fib-Symposium" Keep Concrete attractive", Budapest.

CEMEX. (2019). Carbon & Steel Fiber Reinforced Concrete. Retrieved April, 12, 2019, from https://www.cemexusa.com/products-and-services/concrete/types-of-concrete/fiber-reinforced-concrete

Chik, F. A. W., Jaya, R. P., Bakar, B. H. A., & Johari, M. A. M. (2011). Effect of rice husk ash to the performance of concrete block. *International Journal of Applied, 1*(3).

Denarié, E., & Brühwiler, E. (2006). Structural rehabilitations with ultra-high performance fibre reinforced concretes (UHPFRC). *Restoration of buildings and monuments Bauinstandsetzen und Baudenkmalpflege, 12*(5/6), 453-468.

Dong, Y. (2018). Performance assessment and design of Ultra-High Performance Concrete (UHPC) structures incorporating life-cycle cost and environmental impacts. *Construction and Building Materials, 167*, 414-425.

Foong, K. Y., Alengaram, U. J., Jumaat, M. Z., & Mo, K. H. (2015). Enhancement of the mechanical properties of lightweight oil palm shell concrete using rice husk ash and manufactured sand. *Journal of Zhejiang University-SCIENCE A, 16*(1), 59-69.

Gelardi, G., & Flatt, R. J. (2016). Working mechanisms of water reducers and superplasticizers *Science and Technology of Concrete Admixtures* (pp. 257-278).

Gergely, P., & Lutz, L. (1968). Maximum crack width in reinforced concrete flexural members. Causes, mechanism, and control of cracking in concrete, SP-20. *America Institute Concrete, 10*(12), 87-117.

Givi, A. N., Rashid, S. A., Aziz, F. N. A., & Salleh, M. A. M. (2010). Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. *Construction and Building Materials, 24*(11), 2145-2150.

Graeff, A. G., Pilakoutas, K., Neocleous, K., & Peres, M. V. N. (2012). Fatigue resistance and cracking mechanism of concrete pavements reinforced with recycled steel fibres recovered from post-consumer tyres. *Engineering Structures, 45*, 385-395.

Graybeal. (2007). Compressive behavior of ultra-high-performance fiber-reinforced concrete. *ACI Materials Journal, 104*(2), 146.

Habert, G., Denarié, E., Šajna, A., & Rossi, P. (2013). Lowering the global warming impact of bridge rehabilitations by using Ultra High Performance Fibre Reinforced Concretes. *Cement and concrete composites, 38*, 1-11.

Hakeem, I. Y. A. (2011). *Characterization of an Ultra-High Performance Concrete.* (Master of Science), King Fahd University of Petroleum & Minerals, Saudi Arabia.

Hassan, A., Jones, S., & Mahmud, G. (2012). Experimental test methods to determine the uniaxial tensile and compressive behaviour of ultra high performance fibre reinforced concrete (UHPFRC). *Construction and Building Materials, 37*, 874-882.

Huang, Gao, X., Wang, H., & Ye, H. (2017). Influence of rice husk ash on strength and permeability of ultra-high performance concrete. *Construction and Building Materials, 149*, 621-628.

Huang, Kazemi-Kamyab, H., Sun, W., & Scrivener, K. (2017). Effect of replacement of silica fume with calcined clay on the hydration and microstructural development of eco-UHPFRC. *Materials & Design, 121*, 36-46.

Hylands, K., & Shulman, V. (2003). *Civil engineering applications of tyres*: Viridis.

Jamil, M., Khan, M., Karim, M., Kaish, A., & Zain, M. F. M. (2016). Physical and chemical contributions of Rice Husk Ash on the properties of mortar. *Construction and Building Materials, 128*, 185-198.

Joe, C. D., Moustafa, M. A., & Ryan, K. L. (2017). Cost and Ecological Feasibility of using UHPC in Highway Bridges: Nevada. Dept. of Transportation.

Kang, S.-T., & Kim, J.-K. (2011). The relation between fiber orientation and tensile behavior in an Ultra High Performance Fiber Reinforced Cementitious Composites (UHPFRCC). *Cement and Concrete Research, 41*(10), 1001-1014.

Kang, S.-T., Lee, Y., Park, Y.-D., & Kim, J.-K. (2010). Tensile fracture properties of an Ultra High Performance Fiber Reinforced Concrete (UHPFRC) with steel fiber. *Composite structures, 92*(1), 61-71.

Karim, M., Zain, M. F. M., Jamil, M., & Lai, F. (2013). Fabrication of a non-cement binder using slag, palm oil fuel ash and rice husk ash with sodium hydroxide. *Construction and Building Materials, 49*, 894-902.

Kim, S. W., Park, W. S., Jang, Y. I., Feo, L., & Yun, H. D. (2015). Crack damage mitigation and shear behavior of shear-dominant reinforced concrete beams repaired with strain-hardening cement-based composite. *Composites Part B: Engineering, 79*, 6-19.

Kusumawardaningsih, Y., Fehling, E., & Ismail, M. (2015). UHPC compressive strength test specimens: Cylinder or cube? *Procedia engineering, 125*, 1076-1080.

Lampropoulos, A., Paschalis, S. A., Tsioulou, O., & Dritsos, S. E. (2016). Strengthening of reinforced concrete beams using ultra high performance fibre reinforced concrete (UHPFRC). *Engineering Structures, 106*, 370-384.

Larsen, I. L., Aasbakken, I. G., O'Born, R., Vertes, K., & Thorstensen, R. T. (2017). *Determining the Environmental Benefits of Ultra High Performance Concrete as a Bridge Construction Material.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Leade, C. (2019). Leade New Materials Co., Ltd. Retrieved 8th January, 2020, from https://www.czleade.com/product_category/Concrete-Fiber.html

Ling, I., & Teo, D. (2011). Properties of EPS RHA lightweight concrete bricks under different curing conditions. *Construction and Building Materials, 25*(8), 3648-3655.

Martín-Sanz, H., Chatzi, E., & Brühwiler, E. (2016). *The use of ultra high performance fibre reinforced cement—based composites in rehabilitation projects: A review.* Paper presented at the Proceedings of the 9th International Conference on Fracture Mechanics of Concrete and Concrete Structures FraMCoS-9, Berkeley, CA, USA.

Mehta. (1992). Rice Hush Ash-A unique supplementary cementing material. *Advances in concrete technology*.

Mohseni, E., Khotbehsara, M. M., Naseri, F., Monazami, M., & Sarker, P. (2016). Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina. *Construction and Building Materials, 111*, 429-439.

Nguyen, V. T. (2011). *Rice husk ash as a mineral admixture for ultra high performance concrete.* (Doctorate degree), Delft University of Technology.

Nicolaides, D., Kanellopoulos, A., Savva, P., & Petrou, M. (2015). Experimental field investigation of impact and blast load resistance of Ultra High Performance Fibre Reinforced Cementitious Composites (UHPFRCCs). *Construction and Building Materials, 95*, 566-574.

Noorvand, H., Ali, A. A. A., Demirboga, R., Farzadnia, N., & Noorvand, H. (2013). Incorporation of nano TiO2 in black rice husk ash mortars. *Construction and Building Materials, 47*, 1350-1361.

Paschalis, S. A., & Lampropoulos, A. P. (2015, June 1-3,). *Size effect on the flexural performance of ultra high performance fiber reinforced concrete (UHPFRC).* Paper presented at the In HPFRCC-7 7th RILEM Conference on High Performance Fiber Reinforced Cement Composites, Stuttgart, Germany.

Pilakoutas, K., Neocleous, K., & Tlemat, H. (2004). Reuse of tyre steel fibres as concrete reinforcement. *Proceedings of the ICE-Engineering Sustainability, 157*(3), 131-138.

Pode, R. (2016). Potential applications of rice husk ash waste from rice husk biomass power plant. *Renewable Sustainable Energy Rev., 53*, 1468–1485.

Prem, P. R., Murthy, A. R., Ramesh, G., Bharatkumar, B. H., & Iyer, N. R. (2015). Flexural behaviour of damaged RC beams strengthened with ultra high performance concrete. *Advances in Structural Engineering*, 2057-2069.

Pyo, El-Tawil, S., & Naaman, A. E. (2016). Direct tensile behavior of ultra high performance fiber reinforced concrete (UHP-FRC) at high strain rates. *Cement and Concrete Research, 88*, 144-156.

Rabehi, B., Ghernouti, Y., Li, A., & Boumchedda, K. (2014). Comparative behavior under compression of concrete columns repaired by fiber reinforced polymer (FRP) jacketing and ultra high-performance fiber reinforced concrete (UHPFRC). *Journal of Adhesion Science and Technology, 28*(22-23), 2327-2346.

Rahman, M., Muntohar, A., Pakrashi, V., Nagaratnam, B., & Sujan, D. (2014). Self compacting concrete from uncontrolled burning of rice husk and blended fine aggregate. *Materials & Design, 55*, 410-415.

Rong, Z., Sun, W., & Zhang, Y. (2010). Dynamic compression behavior of ultra-high performance cement based composites. *International Journal of Impact Engineering, 37*(5), 515-520.

Rossli, S. A., & Ibrahim, I. S. (2012). Mechanical properties of recycled steel tire fibres in concrete: Technical Report, Faculty of Civil Engineering, University Technology Malaysia.

Safdar, M., Takashi Matsumoto, and Ko Kakuma. (2016). Flexural behavior of reinforced concrete beams repaired with ultra-high performance fiber reinforced concrete (UHPFRC). *Composite structures, 157*, 448-460.

Sheffield, U. o. (2001). United Kingdom Patent No.

Shihada, S. M., & Oida, Y. M. (2013). Repair of pre-cracked RC beams using several cementitious materials. *Journal of Scientific Research and Reports*, 655-664.

Standards, B. (2002). 1008: 2002, Mixing Water for Concrete-Specification for Sampling, Testing, and Assessing the Suitability of Water, Including Water Recovered From Processes in the Concrete Industry, as Mixing Water for Concrete. London.

Stengel, T., & Schießl, P. (2009). *Life Cycle Assessment of UHPC Bridge Constructions: Sherbrooke Footbridge, Kassel Gärtnerplatz Footbridge and Wapello Road Bridge.* Silesian University of Technology.

Sudarshan, N., & Rao, T. C. (2017). Experimental Investigation of UHPFRC Cube and Cylinder Compression Test at Elevated Temperature. *Open Journal of Civil Engineering, 7*(02), 282.

Tanarslan, H. (2017). Flexural strengthening of RC beams with prefabricated ultra high performance fibre reinforced concrete laminates. *Engineering Structures, 151*, 337-348.

Tayeh, Abu Bakar, Johari, & Voo. (2013). Evaluation of bond strength between normal concrete substrate and ultra high performance fiber concrete as a repair material. *Procedia engineering, 54*, 554-563.

Tayeh, Abu Bakar, B. H., Johari, M. A., & Zeyad, A. M. (2013). Flexural strength behavior of composite UHPFC-existing concrete. . *Advanced Materials Research, 701*, 32-36.

Trading Economics. (2019). Nigeria Population. Retrieved April 26th, 2019, from https://tradingeconomics.com/nigeria/population

Tuan, Ye, G., Breugel, V. K., & Copuroglu, O. (2011). Hydration and microstructure of ultra high performance concrete incorporating rice husk ash. *Cement and Concrete Research, 41*(11), 1104-1111.

Van Tuan, N., Ye, G., Van Breugel, K., Fraaij, A. L., & Dai Bui, D. (2011). The study of using rice husk ash to produce ultra high performance concrete. *Construction and Building Materials, 25*(4), 2030-2035.

Voo, Y. L., Foster, S. J., & Voo, C. C. (2014). Ultrahigh-performance concrete segmental bridge technology: Toward sustainable bridge construction. *Journal of Bridge Engineering, 20*(8), B5014001.

Wang, Gao, X., Li, Q., & Yang, Y. (2018). Influence of splitting load on transport properties of ultra-high performance concrete. *Construction and Building Materials, 171*, 708-718.

Wang, B., Xu, S., & Liu, F. (2016). Evaluation of tensile bonding strength between UHTCC repair materials and concrete substrate. *Construction and Building Materials, 112*, 595-606.

Wille, K., El-Tawil, S., & Naaman, A. E. (2014). Properties of strain hardening ultra high performance fiber reinforced concrete (UHP-FRC) under direct tensile loading. *Cement and concrete composites, 48*, 53-66.

Williams, P. T. (2013). Pyrolysis of waste tyres: a review. *Waste management, 33*(8), 1714-1728.

Yang, I. H., Joh, C., & Kim, B. S. (2011). Flexural strength of ultra high strength concrete beams reinforced with steel fibers. *Procedia engineering, 14*, 793-796.

Yin, H., Teo, W., & Shirai, K. (2017). Experimental investigation on the behaviour of reinforced concrete slabs strengthened with ultra-high performance concrete. *Construction and Building Materials, 155*, 463-474.

Yoo, & Banthia, N. (2017). Mechanical and structural behaviors of ultra-high-performance fiber-reinforced concrete subjected to impact and blast. *Construction and Building Materials, 149*, 416-431.

Yoo, Banthia, N., & Yoon, Y. S. (2016). Mitigating early-age cracking in thin UHPFRC precast concrete products using shrinkage-reducing admixtures. *PCI Journal*, 39-50.

Yoo, Min, K.-H., Lee, J.-H., & Yoon, Y.-S. (2014). Shrinkage and cracking of restrained ultra-high-performance fiber-reinforced concrete slabs at early age. *Construction and Building Materials, 73*, 357-365.