Combined effect of mineral admixtures and fine aggregate on the mechanical properties of ultrahigh performance concrete

Nguyen Duc Vinh Quang¹,², Olga Aleksandrova² and Svetlana Samchenko²
¹ Hue Industrial College, Hue City, Vietnam
² Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
E-mail: ndvquang@hueic.edu.vn

Abstract. The aim of this study was to determine combined effect of mineral admixtures namely fly ash, silica fume as an alternative for cement, and fine aggregate including natural whiter sand (NWS) and finely ground quartz sand as partial replacement of natural river sand (NRS) on the mechanical properties of ultrahigh performance concrete (UHPC) containing steel fiber. Concrete was produced by replacing NRS with 22% up to 100% of NWS of 5-1800 µm fraction by weight of NRS, in UHPC containing 20% of fly ash combined with silica fume at the replacement levels of 5 to 15% contributed to improved mechanical properties. Detailed, compressive strength of UHPC obtained values 122, 128, 117, 115.3, and 118.5 MPa respectively. Similar results were also observed for the splitting tensile strength attained at 11.6, 11.9, 11.5, 10.5, 10.2 MPa, respectively, while flexural strength values range between 18.8 to 25.4 MPa. These values higher than compared to that of the NRS reference specimens without containing NWS at 28 days of curing. The achieved experimental results demonstrated that the addition of locally available NWS can be a good substitute for NRS, and therefore, can be effectively used in construction activities, which in turn reduces the depletion on the NRS resources. Furthermore, utilization of by-product materials reduces the carbon footprint of cementitious composites production as well as environmental pollution concerns.

1. Introduction
Concrete is one of the most universally adopted material in the present world. But even after this, it has number of drawbacks in terms of extreme loading, high permeability, and carbon dioxide emission. To overcome this, ample of research work has been conducted within the last decades to obtain a concrete having higher strength, enhanced durability, and better impermeability along with lesser CO₂ emission.
Vietnam is a developing country, so besides the need to develop energy sources to serve the development of society, then the development of infrastructures such as bridges, roads, metro, tunnels, high-rise buildings ... it also play a key role in economic growth and social development. In recent years, constructions are increasingly large-scale, so requires demands have to type high-performance
concrete serving for special projects such as the construction of basement structures, thin slabs, impact-resistant structures... etc. These types of concrete must meet the technical requirements like high strength and toughness, size stability, adhesive-resistant, no stratification, resistance to cracking and corrosion-resistant in corrosive medium... etc, suitable for the climatic conditions of Vietnam. 

Ultra high-performance concrete (UHPC) containing steel fiber was one excellent choice to do that. Since it was introduced in the early 1990s, UHPC is attracting increasing interests worldwide due to having a lot of advantages more than compared with conventional concrete structures, for example, the superior mechanical properties and durability [1, 2], less negative environmental impact [3, 4], resistance against environmental degradation [2], resistance against fire [5], ductile behavior and excellent anti-seismic property [2, 6]... etc. UHPC is composite stuff that usually consists of cement, fine reactive mineral admixtures (e.g., silica fume and fly ash), fine aggregate (e.g., fine sand, quartz powder), steel fiber for reinforcement and a high dosage of superplasticizer for satisfactory fluidity at very low water-to-cementitious materials ratio [7-12] in its composite mix. It can obtain compressive strengths not less than 150 MPa, flexural strength more than 25 MPa tensile strength greater than 8.5 MPa, excellent durability and toughness, costs and energy reduction [9, 13-15]. The use of steel fiber and coarse aggregate is excluded in mixes lead to reduces micro-cracks that are present in the coarse aggregate and in the interfacial transition zone between the paste matrix and coarse aggregate. These micro-cracks can increase the permeability of concrete. Hence, the exclusion of coarse aggregate is necessary to improve the strength and durability of concrete [16, 17]. Besides, with low permeability characteristics lead to it performs much better under harsh climate conditions and in marine environments, consequently reducing maintenance and repair costs [18]. In the production of UHPC, the added fibres (most likely steel fibres) also play a very important role in improving its mechanical properties. Abbas et al. [19] investigated the effect of steel fibers on the mechanical and durability properties of ultra-high performance concrete (UHPC) containing mix proportion, expressed as parts of cement/silica fume/quartz powder/quartz sand/superplasticizer = 1:0.2:0.3:1:2.3:5 ( % by cement mass). A steel fiber content of (1, 3, and 6%) by total weight of mixture with varying steel fiber lengths (8, 12, and 16mm) were tested. The overall results indicated that the increased mechanical properties as the fiber dosage increased. Besides, the durability properties of UHPC also improved at higher fiber dosage. An addition of steel fiber with different fiber contents (0, 1%, 2%, and 3%) and three shaped fibers (straight, corrugated, and hooked-end fibers) to ultra-high-performance concrete has a beneficial effect on its several mechanical properties, such as UHPC mixes containing cement (784kg) + SF (261kg) + Sand (1045kg) + Water (171kg) + SP (20.9kg) + straight steel fibers at 3% by the volume of concrete, after 28 days of curing flexural strength obtained over 35 MPa, meanwhile compressive strength attained over 150 MPa decreased by 48% and 59% compared to those with the same amount of hooked-end and corrugated fibers. Besides, the flowability also decreased by 45.1% and 51.2% respectively. Moreover, the new constitutive model for flexural load-deflection curve with correlation coefficient over 0.9 was proposed [20]. Using several types of fine aggregates such as natural whiter sand and finely ground quartz sand instead of natural river sand plays a role as micro filler in reducing the maximum paste thickness, leading to lower porosity in the matrix to meet the need for high degree of compactness and high strength. The most widely used fine aggregate for the construction of UHPC is the natural sand extracted from the river beds. With the increase in the construction activities, the demand for river sand has increased exponentially causing the depletion and has become scarce due to the excessive and non-scientific methods of mining from the river beds, further causing environmental threats like lowering of the water table, sinking of the bridge piers, sliding of river shores, etc. For this reason, there is an urgent need for the identification of an alternate material for the replacement of river sand in the preparation of UHPC which in turn depends on several factors such as their availability, physical properties, mechanical properties and chemical ingredients [21-24]. In addition to this, the industrialization and modernization of the country, the industry of Vietnam is being invested, developed strongly. Along with the growing production of products, energy, fuels serving the development of the national economy, the development of many industries increases more and more industrial waste. By which, the coal-fired power plants (CFTP)
industry is an indispensable power source. As the demand for power increases, the amount of fly ash (by-products of coal combustion at high temperatures) produced from thermal power stations in Vietnam is increasing year by year. However, this industrial by-product has not been properly utilized rather it has been neglected like a waste substance, which one of the major sources of environmental pollution more and more serious in Vietnam. According to the adjustment of the National Electricity Development Master Plan for the period of 2011-2020, with the consideration to 2030, going to be 32 plants by 2020 and 51 by 2030. However, to date, the ash generated from CFTP used as a construction material is very low compared to the amount generated, about 10% is used, and 90% is buried. The coal ash wastes from the CFTPs include two parts, the rough ash of coal ash at the bottom of the kiln accounts for about 25% to 30%, and the rest is fly ash (fine-grained ash, spherical, smooth surface) accounts for about 65-70%. For the time being, the annual FA production is about 12.2 million tonnes from the 23 operational thermal power plants. Accordingly, the amount of untreated coal ash is expected to reach 109 million tons by 2020, up to 248 million tons by 2025, and 422 million tons by 2030s. So in the next few years, if no solutions are developed, the amount of ash could increase so much that there is no room for storage. Up to the year 2030 to manage the ash dump with an area of more than 28,000 hectares (assuming a depth of 2m), distributed along the length of the country through large power centers from the region North, Central to the Mekong Delta. Apparently, the problem of ash handling at CFTP in Vietnam is very urgent, posing challenges for environmental protection and CFTP development. Currently, Vietnam is facing environmental problems from the development of coal-fired power plants [25-27]. On the other hand, increase in urbanization demands the growth of infrastructure, which in turn increases the production of the most widely used binder - ordinary Portland cement. Cement is the largest manufactured product on Earth by mass. It is the second most used substance in the world after water. It is estimated that around 50% of world’s OPC is consumed to make nearly 11 billion tonnes of concrete per year, while rest is used for mortars, stucco, screeds, coatings, and other applications. The annual production of Portland cement, estimated at 4.1 billion tons in 2018, approximately 900 kg of CO$_2$ is released per one tonne of cement produced. This estimation equates over 3 billion tonnes of CO$_2$ per year. Thus, cement industry is responsible for approximately 5–7% of total CO$_2$ emissions [28, 29]. Not only CO$_2$ releases from cement plants, but also SO$_2$ (sulfur dioxide), NO$_x$ (nitrous oxides) contribute to greenhouse effect and acid rain [30].

According to the Ministry of Construction (Vietnam) has reported that the demand for cement-consuming this 2020 year would achieve about 101 - 103 million tons, an increase of 4-5% over 2019 figures, the total number of Vietnamese cement production lines to 86 (74 plants) in 2020, with a combined installed capacity of 105.84 Mt per year. In Vietnam, approximately 800 kg of CO$_2$ is released per one tonne of Portland cement produced (TCVN 2682:1992). As such, at the time of 2020, the cement consumption around 105 million tonnes, assuming that all products are Portland cement, it’s tantamount to 79.7Mt the CO$_2$-emissions. This is a number worth thinking about and finding measures to reduce minimize its. To curtail these emissions, there is a need to seek an alternative to partially replace cement with environmentally friendly cementitious composite to reduce the adverse environmental impact of concrete production. One effective alternative to mitigate air pollution is utilization of by-products (e.g., silica fume and fly ash) as partial replacement of cement lead to help in the reduction of CO$_2$ emissions by reducing the amount of cement consumption. Therefore, the reduction in cement consumption has a benefit of reducing CO$_2$ emissions. The substitution of OPC with by-products supplementary cementitious material also enhances the mechanical properties and improves the durability of concrete by consumption of Ca(OH)$_2$ through the pozzolanic reaction and pore refinement (reduction in mean pore size). In recent years the utilization of industrial by-products is gaining momentum with increasing environmental awareness and its likely hazardous effects [31]. Quang N D V et al. [32] studied the mechanical strength and durability properties of HPC containing mineral admixtures consists of 10% of SF combines with FA (20, 30 and 40%) to partial replacement of cement and 20% sand powder as NRS substitute acts as filler material in concrete. The results demonstrated that there is a synergy between FA and SF, the properties of HPC improved both long term durability and strength of its. Concretes with 20%, 30% and 40% FA class F plus 10% SF
received values of compressive strength at 87.92, 90.76, and 91.14 MPa, respectively. Similarly, the splitting tensile strength obtained more than 6 MPa, while flexural strength values range between 9.11 to 9.35 MPa after 28 days of curing. Furthermore, the durability properties in the corrosion environment, water absorbivity, permeability, and abrasion were also covered in this experimental program. On the other hand, Quang N D V et al. [33] in a recent study on the influence of SF and FA combined with quartz powder on properties of HPC. Additions of SF into the HPC were 0%, 5%, 7.5%, 10% and 12.5% along with Fly ash (30%) by weight of cement content, combined with partial replacement of NRS by 20% sand powder kept fixed for all mixes. Test results indicated that the mechanical properties of HPC were improved to a great extent at 28 days when cement used in concrete was replaced by SF. A 10% content of SF + 30% of FA resulted in a 10% increase in compression strength, a 7.3% increase in tensile splitting strength and a 19% increase in flexural strength. In addition, properties such as water absorbivity, permeability, and abrasion also improved significantly. The increasing rate of urbanization and industrialization has lead to overexploitation of natural resources such as natural river sand, which is giving rise to sustainability issues. It has now become imperative to look for alternatives to constituent materials of concrete. Interior field sand (natural whiter sand) of 100..1200 µm fraction and finely ground quartz sand with particle sizes of 5 to 63 µm, is one such promising material which can be used as an alternative to natural sand in UHPC manufacturing. UHPC has been successfully employed in various construction projects around the world [5, 7, 18, 34-36]. However, applications of UHPC in the Vietnam construction industry are numerous restrictions due to the lack of adequate design provisions. The main objective of this research to investigate the effects utilization of industrial by-products typically including fly ash, silica fume combined with fine aggregates likes natural whiter sand and finely ground quartz sand instead of natural river sand to produce UHPC containing steel fiber with low water-to-binder ratios of 0.3 and 0.25, with and without the addition of natural river sand. The mechanical properties consist of compressive strength, splitting tensile strength and flexural strength at different ages were experimentally evaluated. It is anticipated that UHPC can replace conventional concrete in various structural applications, including precast and cast-in-place concrete applications, due to its improved structural durability and extended service life. At the same time also shows that utilization of industrial waste by-products locally available materials in Vietnam has become an attractive alternative to disposal. On the other hand, the use of local materials for developing UHPC is beneficial in saving energy and reducing the concrete cost.

2. Materials and methods

2.1. Materials composition and proportions

For this research program, the binder consists of Portland cement PC40 of company Luks Cement (Vietnam) Limited, accordance with TCVN 7711-2013 with compressive strength at 3 days (34 MPa) and 28 days (50 MPa), initial setting time 130 minute and final setting time 170 minute, content C3A is 2.49 % and content C4AF +2CA is 21.23 %, specific gravity of cement 3.15 g/cm³ was used in this study. Mineral admixtures were utilized due to its pozzolanic reactivity and filling effect [33] consisting of Sikacrete® PP1 – Sika Limited Vietnam in dry densified form, particle size < 0.1µm, specific gravity approx. 2.15 g/cm³ complies with ASTM C1240, and Class F fly ash of thermal power plants Pha Lai was used, conformity with standard TCVN 10302-2014 [32]. The chemical components and physical properties of these three binder are presented in Table 1. Three kinds of fine aggregate (clean, dry) in Hue (Vietnam) conforming to TCVN 7570-2006 and TCVN 10796-2015 used for UHPC mixes comprise natural sand from Huong river with specific gravity 2.65 g/cm³, fineness modulus of 2.905; natural whiter sand (Besides, it known by a different name is interior field sand) with average particle size of 0.1÷1.8 mm and finely ground quartz sand (FGQS) milled from NWS with average particle size of 5 ÷ 63 µm instead of NRS plays a role as micro filler. The particle size distribution curves of these materials are shown in Fig. 1. Superplasticizer (SP) used in this study is Sika®ViscoCrete® 8100 – Sika Vietnam, density 1.09 kg/liter with content was fixed constant at 1.8%
by weight of the binder, and Dramix® 3D steel fiber 65/35 (0.55mm diameter, 35mm length, and aspect ratio of 65) as shown in Table 2, conforming to TCVN 12392-1:2018 with content was kept constant at 100kg/m³ for all mixes. The potable water is used for making concrete mixtures and curing specimens concrete. To investigate the improvement effect of mineral admixtures and fine aggregate on mechanical properties of UHPC with different matrix strength, twelve mixtures were prepared with water-to-binder ratio of 0.25 was used by which mineral admixtures was also added as a cement replacement (25÷47.5% by weight) including fly ash contents of 20%, 30% and 40% and silica fume contents of 5%, 7.5%, 10%, 12.5% and 15% by mass of cement, respectively. The mix proportions of UHPC are provided in Table 3.

**Table 1.** Chemical composition of cementitious materials used in this study

| Components of the binder | Chemical composition (% by mass) |
|--------------------------|----------------------------------|
| Cement                   | SiO₂  20.59, Al₂O₃  3.77, Fe₂O₃  5.06, CaO  62.12, MgO  1.72, SO₃  2.1, LOI  - |
| Fly ash (class F)        | 57.43, 24.05, 6.06, 0.68, 0.96, 0.32, 0.31, 5.74 |
| Sikacrete® PP1           | 92.48, 86.9, 19.1, 0.32, 0.85, 0.31, 1.69 |
| Ground quartz sand       | 99.7, 0.044, 0.04, 0.052, 0.036, 0.036, 0.04 |

**Table 2.** Physical properties of Dramix® 3D steel fiber.

| Index | Diameter (mm) | Length (mm) | Aspect ratio (l/d) | Tensile strength (MPa) | Young’s modulus (MPa) | Specific gravity |
|-------|---------------|-------------|-------------------|------------------------|-----------------------|------------------|
| Unit  | 0.55          | 35          | 65                | 1.30                   | 200.000               | 7.85             |

![Grading curve of natural river sand](image1a.png)

**Figure 1.** Particle size distribution of fine aggregate.

2.2. Mixing and sample preparation

In this study, all mixtures were prepared the same mixing process comprise the following steps: (1) First, in order to prevent agglomeration, and also to promote uniform distribution of the very fine particles, all fine aggregate consists of natural sand and grinding sand powder were mixed in the dry state for 2 min; (2) Thereafter, cementitious materials including cement, fly ash, and silica fume was added and mixing resumed for another 5 min; (3) Subsequently, steel fibers were added gradually and mixing continued for another 3 min until steel fiber was fully dispersed; (4) Afterward, water was mixed with superplasticizer were added gradually until the mixtures became homogeneous at fluid form, about after 10 min; (5) After mixing, concrete was poured in a molds. The specimens with molds were kept in the room at temperatures ranged from 28±2°C until 24 hours then removed from the mold. After that, specimens were cured in the fresh-water tank until the designed age of 3, 7, 14,
21, 28, and 135 days. Each type of freshly mixed concrete was cast into cube specimens 100x100x100 mm, 100x200 mm cylindrical specimen, prismatic 100x100x400 mm were prepared for the compressive, splitting tensile, and flexural tests, respectively.

**Table 3.** Mix proportions of the concrete mixtures, in kg/m$^3$

| Mixture No | Cementitious materials, kg/m$^3$ | Fine aggregates, kg/m$^3$ | Water | Super plasticizer (W+SP) /Cm | Slump (mm) |
|------------|----------------------------------|--------------------------|-------|-----------------------------|-----------|
|            | Cement | Silica fume | Fly ash | Steel fiber | NRS | NWS | GQS | (kg) | (%) | (kg) | (kg) | (kg) | (%) | kg | - | (mm) |
| UC         | 837    | 7.5        | 68      | 0          | 0   | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U1         | 656    | 7.5        | 68      | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U2         | 566    | 7.5        | 68      | 30         | 272 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U3         | 475    | 7.5        | 68      | 40         | 362 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U4         | 611    | 12.5       | 113     | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U5         | 588    | 15         | 136     | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U6         | 679    | 5.0        | 45      | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U7         | 656    | 7.5        | 68      | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U8         | 634    | 10         | 91      | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U9         | 611    | 12.5       | 113     | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |
| U10        | 588    | 15         | 136     | 20         | 181 | 100 | - | 962 | - | 271 | 226 | 1.8 | 17.5 | 0.25 |

**Table 4.** Compressive strengths of the cube specimens at different ages

| Mixture No | Compressive strength (MPa) | Splitting tensile strength | Flexural Strength (MPa) |
|------------|---------------------------|---------------------------|-------------------------|
|            | 3 days | 7 days | 14 days | 21 days | 28 days | 135 days | 28 days | 28 days |
| UC         | 71     | 90     | 98      | 104     | 107     | 112      | 7.2     | 10.4    |
| U1         | 64     | 80     | 89      | 94      | 100     | 106      | 6.7     | 9.8     |
| U2         | -      | 56     | 73      | 79.7    | 82.5    | 91       | 6.1     | 9.5     |
| U3         | -      | 66     | 78.6    | 82      | 83.3    | 96       | 7.6     | 12.3    |
| U4         | 69     | 83     | 94      | 98      | 99      | 108      | 8.6     | 17.6    |
| U5         | 65     | 81.5   | 90      | 98      | 102     | 109      | 8.4     | 20.5    |
| U6         | 73.5   | 93.3   | 108     | 110.5   | 115     | 117      | 7.5     | 16.4    |
| U7         | 107    | 115    | 117     | 119.5   | 122     | 135      | 11.6    | 28.4    |
| U8         | 110    | 117    | 119     | 121     | 128     | 137      | 11.9    | 29.0    |
| U9         | 104    | 108    | 111     | 114     | 117     | 136      | 11.5    | 26.5    |
| U10        | 98     | 104    | 108     | 112     | 115.3   | 125      | 10.5    | 22.4    |
| U11        | 95     | 103.5  | 107     | 112     | 118.5   | 124      | 10.2    | 21.4    |

2.3. Experimental methods

2.3.1 Test on fresh properties

The flowability of all UHPC mixtures containing steel fibers was checked immediately after the mixing process ended to evaluate the workability of fresh concrete, conformable to ASTM-C1611 [14]
and slump test was done conforms to the ASTM-C143/C143M-12 test method. Value fluidity of concrete mixtures in this study the range of 240-250mm

2.3.2 Mechanical Properties
A 2000 kN capacity universal testing machine used to test the compressive strength of cube specimens 100³ mm at the ages of 7, 14, 21, 28 and 120 days in accordance with TCVN 3118:1993. The compressive strength was calculated to follow equation $f_c = \alpha \cdot \frac{P}{F_c}$, where $f_c$ is the compressive strength (MPa), $P$ is compressive load on specimen at failure (N), $F_c$ is the specimen cross-sectional area (mm²) and $\alpha = 0.91$ is conversion ratio. The splitting tensile strength test was conducted on cylindrical specimens of diameter $D = 100$ mm and length $L = 200$ mm were cast at the age of 28 days curing, accord with TCVN 8862:2011 and splitting tensile strength (MPa) was calculated to follow equation: $f_{ct} = \frac{2P}{(\pi \cdot L \cdot D)}$. The flexural strength of UHPC was determined by the method of four-point bending on prism specimens 100x100x400mm at the age of 28 days curing, accord with TCVN 3119:1993 was calculated to follow equation: $f_r = \gamma (P \cdot L)/(\alpha \cdot b^2)$, where: $f_r$ is flexural strength (MPa), $L = 3a = 3b = 300$mm is span of the beam. The experimental result was reported in this study is the average value of three specimens tested.

3. Results and discussion
The test results are summarized in Table 4 and graphically illustrated in Figs. 2 through 4. The experimental results indicate the efficiency of combine four parameters (natural whiter sand and finely ground quartz sand, SF and FA) on the mechanical properties such as compressive strength at 3, 7, 14, 21, 28, 135 days, flexural and splitting tensile strength at 28 days of UHPC. The results also reveal a beneficial advantage on the mechanical properties of ultrahigh-performance concrete in the simultaneous use of steel fiber, fly ash, silica fume and natural whiter sand in the mixtures.

3.1. Compressive strength
The variation in the compressive strength of both fine aggregate types, with and without natural white sand in twelve mixtures from UC to U11 containing steel fiber and fly ash, silica fume as an alternative for cement with difference replace rate by weight of cement, tested were at different ages is presented in Figs. 2 through 3. It was noticed that the compressive quality of all UHPC specimens has grown up with increasing curing time. The effects of fly ash at varying fly ash percentages on the compressive strength in mixes containing 7.5% SF and NRS are illustrated in Figs. 2. The compressive strength of U1-U3 specimens was observed to increase with the age of concrete that is from day 7 to day 135 days. The application of fly ash in mixes has decreased the compressive strength values over the control mix (UC) at an early age. The strength of concrete mixes reduced as the percentage of fly ash is increased, this is due to the slow pozzolanic reaction and dilution effect of FA. In addition, the hydration reaction between fly ash and water is significantly slower than that between cement and water because of the minor difference between their compositions. It can be seen that an increase in the content of fly ash is accompanied by a corresponding increase in the compressive strength of concrete samples at late ages, namely, the reduction in compressive strength of concrete at the age of 7 days was found to be 13%, 39.1%, and 28.3%, while at age 120 days found to be 5.4%, 18.8% and 14.3% for 20%,30% and 40% replacement of cement with fly ash, this proved the strength development gradually at late ages. For this reason, the improvement in mechanical properties could probably be ascribed to the cumulative effects of improved cement hydration coupled with the pozzolanic reactivity of the fly ash. The compressive strength of UC-U3 mixtures achieved strength of 112, 106, 91, and 96 MPa, respectively, at 120 days. From the chart Fig. 3, it is watched that the use of NWS instead of NRS has a significant impact on the development of UHPC’s early compressive strength. The results revealed that the reference group containing fine aggregate is NRS, the three-day compressive strength of the U1-U6 mixtures was achieved values at 64, 69, 65 and 73.5 MPa respectively. Meanwhile, the experimental group containing NWS used as fine aggregate, the three-day compressive strength of the U7 to U11 mixtures
was attained values at 107, 110, 104, 98 and 95 MPa respectively. It was shown that the incorporation of pozzolanic materials with NWS (size 5µm-1.8mm) can enhance the early age compressive strength of UHPC, and the percentage of improvement was between 29.3% and 73.4% at an early age 3 days. Afterward, gradually decrease the strength at later ages, the percentage of improvement was between 4.8% and 29.2% after 120 days. The compressive strength of specimens containing NWS was used as the fine aggregate in substitution of NRS with a level of substitution fully, by which including U7-U11 mixtures obtained values 135, 137, 136, 125 and 124 MPa, respectively, after a period of 120 days. These higher than compared with the reference samples U1, U4, U5 and U6 at level 29.2%, 25.3%, 14.7%, and 5.7%, respectively.

Figure 3. Compressive strength of concrete contains SF and fine aggregate at different content.

Figure 2. Variation of compressive strength with FA content.

Figure 4. Flexural and Splitting tensile strength of specimens at 28-days.

Figure 3 presents the relationship between SF content and compressive strength development of UHPC mixtures with and without NWS at different ages. The increase of UHPC compressive strength was observed by increasing the silica fume content. When silica fume is added to the concrete pozzolanic reaction occurs following equation: \( (C_3S + C_2S) + H_2O \rightarrow C - S - H + CH + SiO_2 \rightarrow C - S - H \). Products C-S-H was created, it not only improves the bond between the cement and the surface of the aggregate but also gives the concrete a much denser matrix. The benefit of this reaction is twofold: increasing compressive strength and decreasing total pores volume. Thereto, the silica fume particles size < 0.1µm can fill the voids created by free water in the matrix. The addition of silica fume can decrease the water demand of the cement paste through increased packing density and thus less
empty voids between the cement particles. However, for given water content, the addition of silica fume more than the limited value will degrade the workability of the mix, which results from decreased strength of concrete. From the results shown in Figure 3, it can be seen that the compressive strength of U1-U6 mixtures in which fine aggregate consists of NRS (78%) combine with FGQS (22%) increased with increasing silica fume content as well as curing time. The increases compressive strength at 28 days as compared to its strength at 3 days were determined as 56.3%, 43%, 56.9%, and 56% for 7.5%, 10%, 12.5%, and 15% silica fume content, respectively. It has been noticed that the rapid strength development occurred between the ages of 3 and 28 days. But after a period of 28-days, there was a slight increase in the compressive strength of U1-U6 specimens until 120th days, at that time the strength of specimens attained values 106, 108, 109 and 117 MPa, respectively. Contrary to the U7-U11 mixtures only including NWS (100%), the compressive strength development of nearly all specimens was reached at early age of 3 days with all SF contents. The highest compressive strength (137 MPa at 120 days) was obtained when the percentage of silica fume was 7.5 % of the cement weight. When increasing dosage of silica fume beyond 7.5 %, the compressive strength started descending. This proves that which is a cause of how the silica fume works both chemically and physically; chemically the silica fume reacts with calcium hydroxide from the hydration of Portland cement which increases the bond strength and physically the silica fume increases the packing density and decreases the pore volume. If higher dosage of silica fume is added there will be a certain amount of silica fume that does not react and remains inert which can be the weakest point in the concrete. The results showed that an optimal content of SF for this type of mix is at 7.5% of cement weight with the criteria’s;

3.2. Splitting tensile strength

The results of splitting tensile strength of UHPC with and without natural white sand (particle sizes of 5 to 1200 µm) were determined after a period of 28-days is shown in Fig. 4. The results show that splitting tensile strength is increased with increasing content of SF from 5% to 12.5% then slightly reduce at 15% in mixes U1, U4, U5 and U6 containing NRS obtained values at 6.7, 8.3, 8.4 and 7.5 MPa, respectively. These indicate that the incorporation of SF improved the splitting tensile strength of Portland-silica fume-fly ash concrete blend. It can be seen from Fig. 5 the UC, U1, U2 mixtures contain SF fixed maintained at 7.5%, prepared at 0.25 water-binder ratio shown gradually decreased strength when the fly ash addition increases from 0% to 30%, only U3 mix with 40% fly ash significantly gained strength as compared to the controlled (UC without FA) mixes. It is worth noting that mixtures using NWS instead of NRS have received values superior splitting tensile strength, with values, received in turn according to the content of silica fume from 5-15% is 11.6, 11.9, 11.5, 10.5 and 10.2 MPa corresponding to models U7, U8, U9, U10, and U11. These higher than compared with the reference samples U1, U4, U5 and U6 at level 78.6%, 33.3%, 24.5% and 36.2%, respectively. The highest value of tensile strength is for U8 contain 80% NWS as a replacement to NRS combine with 7.5% SF and 20% FA, which is 78.6% higher compared to the U1 (100% NRS) sample and reached intensity value at 11.9 MPa. But after the increasing presence of SF content in mixes, tensile strength was gradually reduced. The lowest value is for U11 contain 15% SF, obtained 10.2 MPa value, which still is 36.2% higher than the reference samples U6.

3.3. Flexural strength

Figure 4 shows that the 28-day flexural strength of the concrete mixtures with and without NWS, the test results were between 9.5 and 29.2 MPa. The mixes group consist of (7.5-47.5)% of the cement was replaced with FA (0-40)% combines with 7.5% SF resulted showed were between 9.5 and 12.3 MPa, the lower flexural strength of the concrete compared to the other mixes. Meanwhile, nine series of concrete mixes, with and without NWS was made with partial replacement of cement by equal weight of silica fume (5, 7.5, 10, 12.5 and 15%) combines with 20% FA. The test results flexural strength of U7-U11 specimens was achieved values at 28.4, 29.2, 26.5, 22.4 and 21.4 MPa, respectively, higher compared to the reference (U1, U4-U6) mixes from 1.1 to 3 times.
4. Conclusions

Based on the results of this experimental investigation, the following conclusions are drawn:

1. It is possible to develop UHPC mixtures containing locally available materials. A 120-day compressive strength of 137 MPa was obtained with total cementitious materials of 950 kg/m$^3$ including 7.5% of SF + 20% FA, and NWS. The highest flexural and splitting tensile strength was achieved 29.2 and 11.5 MPa, respectively, after the curing period 28 days. The results showed that an optimal content of SF for this type of mix is at 7.5% of cement weight with the criteria’s;

2. The use of natural white sand (sizes of 5 to 1800 µm) increases the mechanical properties when compared to natural river sand. Especially, the compressive strength development of almost all specimens was reached at early age of 3 days with all SF contents.

3. The achieved experimental results demonstrated that the addition of locally available NWS can be a good substitute for NRS, and therefore, can be effectively used in construction activities, which in turn reduces the depletion on the NRS resources. Furthermore, the utilization of by-product materials decreases the carbon footprint of cementitious composites production as well as environmental pollution concerns. On the other hand, the use of local materials for developing UHPC is beneficial in saving energy and reducing the concrete cost.

References

[1] Brandt A M 2008 Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering Composite Structures, vol. 86(1-3), pp. 3-9, Doi:10.1016/j.compstruct.2008.03.006

[2] Abbas S, Nehdi M L and Saleem M A 2016 Ultra-high performance concrete: Mechanical performance, durability, sustainability and implementation challenges International Journal of Concrete Structures and Materials vol. 10 (3), pp.271–295, Doi:10.1007/s40069-016-0157-4, ISSN 1976-0485/eISSN 2234-1315.

[3] Rodrigues F A, Joekes I 2010 Cement industry: sustainability, challenges and perspectives Environmental Chemistry Letters, vol. 9(2), pp.151–166, Doi:10.1007/s10311-010-0302-2.

[4] Provis J L 2017 Alkali-activated materials Cement and Concrete Research, Cemcon-05270, 9p, Doi:10.1016/j.cemconres.2017.02.009.

[5] Zhou M, Lu W, Song J and Lee G C 2018 Application of Ultra-High Performance Concrete in bridge engineering Construction and Building Materials vol. 186, pp.1256–1267, Doi:10.1016/j.conbuildmat.2018.08.036.

[6] Yu K, Li L, Yu J, Wang Y Ye, J and Xu Q 2018 Direct tensile properties of engineered cementitious composites: A review Construction and Building Materials, vol. 165, pp. 346-362, Doi:10.1016/j.conbuildmat.2017.12.124

[7] Schmidt M and Fehling E 2005 Ultra-high-performance concrete: research, development and application in Europe, 7th International Symposium on Utilization of High Strength High Performance Concrete, vol. 1, 2005, pp. 51–77.

[8] Benjamin A. Graybeal 2007 Compressive behavior of ultra-high performance fiber-reinforced concrete, ACI Materials Journal, vol. 104 (2), pp.146–152.

[9] Shi C, Wu Z, Xiao J, Wang D, Huang Z and Fang Z 2015 A review on ultra high performance concrete: Part I. Raw materials and mixture design Construction and Building Materials, vol. 101, pp. 741–751. Doi:10.1016/j.conbuildmat.2015.10.088

[10] Wang D, Shi C, Wu Z, Xiao J, Huang Z and Fang Z 2015 A review on ultra high performance concrete: Part II. Hydration, microstructure and properties. Construction and Building Materials, 96, 368–377. Doi:10.1016/j.conbuildmat.2015.08.095

[11] Zou F, Tan H, Guo Y, Ma B, He X and Zhou Y 2017 Effect of sodium gluconate on dispersion of polycarboxylate superplasticizer with different grafting density in side chain Journal of Industrial and Engineering Chemistry, vol. 55, pp. 91–100. Doi:10.1016/j.jiec.2017.06.032
[12] Mishra O and Singh S P 2019 An overview of microstructural and material properties of ultra-high-performance concrete Journal of Sustainable Cement-Based Materials, pp. 1-47. doi:10.1080/21650373.2018.1564398.

[13] Wille K, Naaman A and et al. 2011 Ultra-high performance concrete with compressive strength exceeding 150 MPa (22 ksi): A simpler way ACI Materials Journal vol. 108(1), pp. 46-54

[14] Su Y, Li J, Wu C, Wu P and Zhong-Xian Li 2016 Effects of steel fibres on dynamic strength of UHPC Construction and Building Materials, vol. 114, pp. 708–718. doi:10.1016/j.conbuildmat.2016.04.007

[15] Alsalman A, Dang C N and Micah Hale W 2017 Development of ultra-high performance concrete with locally available materials Construction and Building Materials, vol. 133, pp.135–145. Doi:10.1016/j.conbuildmat.2016.12.040

[16] C. Magureanu, I. Sosa, C. Negrutiu, B. Hughes (2012). Mechanical properties and durability of ultra-high-performance concrete, ACI Mater. J. 109 (2) 177–183

[17] Xiong M X, Liew J Y R, Wang Y B, Xiong D X and Lai B L 2020 Effects of coarse aggregates on physical and mechanical properties of C170/185 ultra-high strength concrete and compressive behaviour of CFST columns Construction and Building Materials, vol. 240, 117967. Doi:10.1016/j.conbuildmat.2019.117967

[18] Azmee, N. M., & Shafiq, N. (2018). Ultra-high performance concrete: From fundamental to applications. Case Studies in Construction Materials 9 (2018) e00197, 15p. Doi:10.1016/j.cscm.2018.e00197

[19] Abbas S, Soliman AM & Nehdi ML 2015 Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fiber lengths and dosages Construction and Building Materials, 75, 429-441. Doi:10.1016/j.conbuildmat.2014.11.017

[20] Wu Z, Shi C, He W & Wu L 2016 Effects of steel fiber content and shape on mechanical properties of ultra high performance concrete Construction and Building Materials, vol. 103, pp. 8–14. Doi:10.1016/j.conbuildmat.2015.11.028

[21] Alhozaimy A, Jaafar M S, Al-Negheimish A, Abdullah A, Taufig-Yap Y H, Noorzaei J and Alawad O A 2012 Properties of high strength concrete using white and dune sands under normal and autoclaved curing Construction and Building Materials, vol. 27(1), pp. 218–222. Doi:10.1016/j.conbuildmat.2011.07.057

[22] Akshay C. Sankh, Praveen M. Biradar, Prof. S. J Naghathan, et. al. 2014 Recent trends in replacement of natural sand with different alternatives International Conference on Advances in Engineering & Technology (ICAET-2014, IOSR-JMCE), pp. 59-66, e-ISBN: 2278-1684.

[23] Durga B and Indira M 2016 Experimental study on various effects of partial replacement of fine aggregate with silica sand in cement concrete and cement mortar International Journal of Engineering Trends and Technology, vol. 33(5), pp. 252-256, ISSN: 2231-5381

[24] E. Rahmathulla Noufal, U. Manju 2016 I-sand: An environment friendly alternative to river sand in Reinforced Cement Concrete constructions Construction and Building Materials, vol. 125(30), pp. 1152-1157, Doi:10.1016/j.conbuildmat.2016.08.130

[25] Phan Thu 2016 The risk of pollution from coal-fired power Customsnews.vn, 2016.

[26] Dean Dougn 2019 Vietnam to face an increase in energy demand as economy is growing rapidly The ASEAN Post Team – Vietnam Insider, 2019.

[27] Sen 2020 Leading NGOs urge Vietnam to scrap new coal-fired power projects Vnexpress.net, 2020.

[28] Turner L K and Collins F G 2013 Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete Construction and Building Materials, vol. 43, pp. 125–130. Doi:10.1016/j.conbuildmat.2013.01.023

[29] Jos G J Olivier, Greet J M, Muntean M, Jeroen Peters 2016 Trends in global CO2-emissions, 2016 Report PBL Netherlands Environmental Assessment Agency, 86p.
[30] Valipour M, Yekkalar M, Shekarchi M and Panahi S 2014 Environmental assessment of green concrete containing natural zeolite on the global warming index in marine environments Journal of Cleaner Production, vol. 65, pp. 418-423. Doi:10.1016/j.jclepro.2013.07.055

[31] Liew KM, Sojobi AO, Zhang LW 2017 Green concrete: prospects and challenges. Constr Build Mater 156:1063–1095. https://doi.org/10.1016/j.conbuildmat.2017.09.008

[32] Nguyen Duc Vinh Quang, Aleksandrova O V and Tkach E V 2019 Effect of fly ash and Quartz powder on the properties of high-performance concrete The 3rd Int. Conf. on Transport Infrastructure & Sustainable Development. Construction Publishing House. ISBN: 978-604-82-2893-4. Pp. 503-515

[33] Nguyen Duc Vinh Quang, Bazhenov Y M and Aleksandrova O V 2019 Effect of quartz powder and mineral admixtures on the properties of high-performance concrete Vestnik MGSU, volume 14 Issue 1 (124). ISSN 1997-0935, 2019. Doi:10.22227/1997-0935.2019.1.102-117.

[34] Gu C, Ye G and Sun W 2015 Ultrahigh performance concrete-properties, applications and perspectives Science China Technological Sciences, vol. 58(4), pp. 587-599. Doi:10.1007/s11431-015-5769-4