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Study on the Mechanical Properties of Ecological Engineeredcementitious Composite (ECO-ECC) Which Contained PVA Fiber and recycled Brick Powder Exposed To Low Temperature.

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ABSTRACT:*there are several experiments were studied about the Engineering Cementitious Composite (ECC) after exposure to low and high temperature that focus on Mechanical Properties of ECC, included tensile strength, compressive strength, toughness, young modulus, ductility, flexural strength, durability of ECC after exposure to low and high temperature. But there is no study about Mechanical Properties of Ecological Engineering Cementitious Composite (ECO-ECC) which contained Recycled Brick Powder after exposure to low temperature.In this paper, we were studied about compressive strength, flexural strength and bending strength of ECC that was contained PVA fiber and Clay Break after exposure to low temperature. In this study, the compressive test, flexural test and bending test according to the China Testing Material was carried out two type of concretes: the first one is the normal concrete which use the natural materials and PVA fiber, and the second is the concrete was contained PVA fiber and the recycled material with four difference type of volume combination at* 25%, 50%, 75%, *and* 100% *of Clay Break and used PVA fiber equal* 1.75% *of cement and fly ash. Our specimens were putted in low temperature until the testing day (7days) after demold, and using low temperature are* $0^{o}C$, $-10^{o}C$, $-20^{o}C$, *and* $-30^{o}C$. *PVA played in the important role for increasing strength to the specimen.*

KEYWORDS: *Mechanical Properties, Raw Materials, Brick block, Low temperature, Compressive strength, Flexural strength, Bending Behavior, Recycled brick powder (RBP), Ecological Engineering Cementitious Composite (ECO-ECC), Engineering Cementitious Composite (ECC)*

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I. INTRODUCTION

1.1 Research background

Concrete is a building material with high strength in compression but it is quite brittle with tensile strength maybe 10% of its compressive strength [1]. Concrete is the main material for the modern engineering structure in the world. In report shown that the annual amount of concrete in China is about 900-million-meter cube and the amount of steel is about 20 million tons per year, ranking is the first in the world [2]. It is foreseeable that reinforced concrete will still be the main engineering structure material in China for a long time. As the granular composite material, concrete has micro crack in it due the action of load, shrinkage, bleeding, etc. After loading, micro-cracks are continuously generated and expanded. Concrete is the main material of the reinforced concrete structure has the following deficiencies as below: the tensile strength is low, and it always shows brittle failure in the structure, durability also low, the corrosion of the steel bar is easy to cause cracking and break to the concrete and the toughness also low.

Since the 1900s, the high-performance concrete with superior mechanical properties such as high durability, high strength, and toughness. The important thing to become the high-performance concrete is to add the appropriate amount of fiber (polyvinyl alcohol (PVA) fiber, polypropylene (PE) fiber, steel fiber, plastic fiber, glass fiber, and carbon fiber) can limit the width of the crack, improve its tensile strength, flexural strength, compressive strength, shear strength, especially improve its ductility, toughness, fatigue resistance, resistance impact, bending behavior and other mechanical properties.

In 1992, Victor Li and Leung have added fiber 2% by volume to concrete mix to become the Engineered Cementitious Composite, its mechanical properties are higher if compare to the old. It is shown the ultra-high ductility, its ultimate tensile strain can reach 2% to 6%.

Depending on the experimental studies and the other researchers have discovered many characteristics of ECC in structural applications: ECC has a large tensile strain, the crack width is much smaller than the maximum crack width 2mm, and the micro-crack are good. It has better deformation performance with steel bars, and the tiny cracks generated by ECC can prevent the infiltration of water and improve the toughness and rigidity of the structure, and all the mechanical properties of it are higher.

Under the guidance of the idea of compounding materials and adding fibers, fiber reinforced concrete (FRC) has been favored by a large number of researchers. Fiber reinforced concrete called fiber concrete, if is based on cement slurry, mortar or concrete with metal fiber, inorganic mon-fiber, synthetic fiber or natural organic fiber is a composite material composed of reinforced materials. More than two different materials are combined in a certain way, except that the original characteristics of the original constituent materials are retained. In addition, it also produces a new material with significantly better performance than any of the constituent material. This new material is called “composite”. Composite materials generally contain two phases, one is a continuous phase called “matrix” and the other one is a dispersed phase which can be colloidal granular or fibrous. We often use cement paste, mortar or concrete as the base material, collectively referred to as cement base material or we called cement matrix. When fibers are used as the reinforcing materials, the composite materials formed are collectively called “fiber-reinforced hybrid material” (fiber reinforced cement composite, abbreviated as FRCC).

The American Concrete Association (ACI) believes that fiber-reinforced concrete contains fine aggregates or coarse and fine aggregates. Material composed of hydraulic cement and discontinuous dispersed fibers, dispersed fibers, continuous dispersed fibers, continuous mesh, fabric and long rods do not belong to the reinforcement of dispersed fibers. In china is generally defined. Fiber-reinforced cement-based composite material is based on cement paste, mortar or concrete with non-continuous short fibers or continuous long fibers. Composite material composed of fibers as reinforcement materials (new fiber-reinforced cement-based composite material). Therefore, it can be divided into fiber-reinforced cement and concrete as the matrix fiber-reinforced.

At the present, with the development of transportation infrastructure, construction of highway brides, high-right building, and the special condition of construction were increased. Concrete widely used in many various structures that are exposed to continuous variation in cold regime temperature and moisture content [3]. The mechanical properties of concrete are more complex than the most materials as they are impacted by the environmental condition when it is placed and cured [4]. The is a researcher was carried on the curing of concrete in the extreme cold condition [5,6]. Other studies indicated that the concrete exhibits change in properties as the temperature conditions change [7]. It also is the main building material that is widely used in all kinds of structures almost in the world, by the high requirement of construction, nowadays Engineered Cementitious Composite (ECC) become popular and many infrastructure structures were used as the material building. The best way to improve the concrete’s brittleness is added fiber into concrete mix. There are several types of fibers that can be used for mixing such polyvinyl alcohol (PVA) fiber, polypropylene (PE) fiber, steel fiber, plastic fiber, glass fiber, and carbon fiber and used in a variety situation such as tunnel, industrial floor, precast wall and shotcrete [8]. In ECC mix we generally used PVA fiber, PVA fiber also is cheaper than the other fiber and more popular for the researcher. Engineered Cementitious Composite (ECC) is a kind of fiber reinforced cementitious composite based on the micro and fracture mechanics theory which deals with high strength, durability, toughness, pseudo-strain hardening with a multiples crack pattern during the loading process [9].

In mix design, we generally used natural materials for making concrete, ECC, and other mix. The overring of using natural resource harmful to the environment. Moreover, the construction waste and renovation waste also increase from year to year. The construction waste and renovation waste that have no decorated can polluted to environment. In China, the construction waste is about 40 million to 50 million tons per year and also contain the renovation waste about 13% to 15% of it [10]. All of this waste contains amount of toxic and harmful components that can affect to the soil and underground water, especially at the suburbs and rural areas because landfill sites located at there. In the construction waste and renovation waste contained brick about 11% to 25%, because of large amount of brick block, we were decided to use recycle brick in civil engineering. In the condition of using ECC to construct the structure comprises of cement, fly ash, silica sand, fiber and the chemical admixture.

In this experimental studied, we were used recycled brick powder as the material to replace quartz sand by mass are 0%, 25%, 50%, 75% and 100%, respectively. The specimen has kept in low temperature after demold until testing date. The main point of this research, we studied on the mechanical properties of engineered cementitious composite (ECC) which contained PVA fiber and recycled brick powder after exposure to low temperature.

1.2 Research status

1.2.1 The bending behavior of PVA-ECC

Ultra-high toughness cement-based composite materials (UHTCC), commonly referred to Engineering Cement-based composite materials abroad or called “Engineered Cementitious Composite, ECC” which is designed by the system to show high performance under tensive and shear loads, a ductile fiber-reinforced composite material which was once ranged among the Top Ten New Technologies You Must Know in 2017[11]. UHTCC usually takes cement or cement with fillers or fine aggregates with a particle size of not more than 5mm is used as the matrix, and fiber is used as the reinforcing material. The material design method based on micromechanics, UHTCC with the fiber volume content of only 2% which is medium fiber content of cement-based composite materials, for the short fibers are randomly distributed in the mortar matrix, so conventional production and construction tools are used.

It can be cast and molded by the art, the composite material of the hardened composite material can effectively bridge the crack after cracking and bear the load and gradually pulled out of the matrix as the cracks developed. During this process, the load increased, and a large number of new cracks continued. As a result, the material undergoes hardening strain [12]. This is the result of FRC strain-softening characteristics to achieve steady-state cracking. Source of UHTCC's unique toughness (see Fig. 1.1). The bending test fully embodies UHTCC's multi-crack non-cracking and ultra-high toughness characteristics unlike metal materials, UHTCC strain hardening is a process of damage accumulation, so it is also called quasi-strain hardening (Pseudo-Strain hardening) [13]. Strain hardening makes UHTCC have ultra-high toughness and fracture Crack energy, in uniaxial tensile test, from cracking to ultimate failure can produce multiple fine cracks, multiple points in saturation state. The crack spacing can be controlled within 100 microns, the maximum strain is greater than 3% [10-12,14].

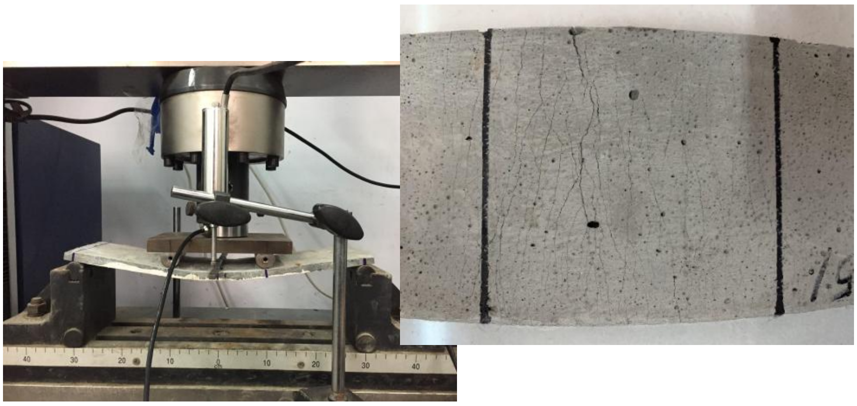


Fig. 1.1.Flexural test and multipul cracking

1.2.2 Demolition and construction waste

Nowadays, the building or demolition waste and clay brick increased significantly. As the reports of European Union (EU) shown that the approximately of 3 million tons of waste are generated in EU 27 each year, being the demolition and construction waste one of the heaviest and most voluminous waste streams. The typical of construction and demolition waste included materials such as brick, concrete, gypsum, wood, glass, plastic, solvents and asbestos [15]. But not for all of the CDW can use, just some of CDW components have a good resource value and also can be reused for any applications in construction activities [16].

For the construction and demolition waste type is high potential to be used in concrete and mortars is the clay bricks and ceramic waste. The use of ceramic waste in concrete has researched for the last few year. The sources of ceramic wastes have report in such studies include crushed clean clay bricks, industrial brick waste and bricks obtained from demolished construction, recovered floor and wall [17].

For the modern digital world is creating a tremendous increase the electronic waste product. For example, the E-plastic waste can be used as a fragmentary substitute for the coarse or fine aggregates in construction industry [18]. The experiment has done on M40 grad concrete mix, the tests were conducted with 0%, 12%, 17% and 22% replacement of coarse aggregates with E-plastic waste. It has shown that the increasing of E-plastic, compressive strength, flexural strength and spit tensile strength of concrete decrease and it was found when the replacement was more than 20% [19].

Construction and demolition waste are the important and essential concern of today's construction industry. The steep of urbanization behavior and variance between demand and supply lead to non-sustainable development in most parts around the world, because of the energy inefficient raw materials adding up the higher cost of all materials for current used in civil engineering [20]. The fast pace of cycle of construction, demolition, and re-construction of the current construction industry consumed 40 million tons of sand and aggregate [21]. The construction industry has generated the amount of construction and demolition and debris encouraging researchers to find the better method for reusing, reducing and recycling them for a sustainable future. The using of recycling concrete as non-virgin material for a new concrete is an effective method for reducing construction and demolition waste (W&D) landfilling, reducing the using of natural materials, which leads to a continuous increase in the recycling rate of such materials [22]. recycling construction and demolition waste to instead sand is a challenging step for researchers all around the world that compared to the coarse aggregates produced from concrete. The recycled sand is a type of additional supplementary cementitious materials that prove to have pozzolanic activity. Thus, many researchers are incorporating recycled sand for enhancing the mechanical properties of mortars and concrete [23]. Recycled sand was incorporated may help to promote for ecological balance and conservation of natural resources.

The recycled sand is used in the past decade, according to Ulsen, waste concrete is processed by impact crushing for sand production. The result shown that it was effective in reducing cement paste content. By adding the optimum dose of superplasticizer, the mortar containing recycled sand can have similar mechanical properties as the standardized river sand. It was also revealed that the behavior of lime mortars was improved, even at an early age, due to the reaction of lime with the constituents. Ceramics sand was used in high-performance concrete. The mechanical properties and water transport properties were not significantly impaired by adding ceramics up to 20%. According to many researches on waste brick shown that the addition of artificial pozzolan improved grinding time and setting times of the cement. A few studies found to recycled aerated concrete blocks because of their highly porous structure, indicated that opportunities in applying aerated concrete waste as sand for load-bearing purposes are minimal. Because of high porosities of aerated concrete blocks and sintered clay brick are limited to incorporate them for recycled coarse aggregates production. The utilization of ACB and SCB as recycled sand can effectively reduce the negative influence of the porous particles on the mechanical and durability properties and the pozzolanic characteristics of the ACB and SCB sand may contribute to strength improvement and internal curing effect of recycled sand may lead to a denser structure of the products of hydration. According to the previous studies, the using of recycled sand as the natural sand may reduce the water/cement ratio and also effect to the flowability and transition zones. Moreover, it was found that low density aggregate can reduce strength of concrete and replacement increased, the strength of concrete was reduced.

The application of using waste bricks as the construction materials if mainly concentrated in China. The research on PVA-ECC was started late in China but the research on ecological ultra-high toughness cement-based composite material is also in the early stage for all researchers. In this paper, the use of waste sintered bricks to instead of quartz sand to prepare the ECO-ECC is not in line with China's sustainable development strategy, but also improve the recycling rate of construction waste and it also good for guiding engineering practice in the further.

1.2.3 Research significance of ecological-ECC

Nowadays, many researchers have studied about engineered cementitious composite that focus on the mechanical properties, the hardening-strain characteristics and multi-crack of PVA-ECC also have been confirmed by relevant scholars. As we known that the PVA-ECC has excellent mechanical properties and durability because of using fine aggregate in mix preparation, the commonly used is quartz sand, its coast is more expensive than coarse aggregates. For the ordinary PVA-ECC used quartz sand. The scholar at home and abroad have conducted research on relevant of PVA-ECC from the sustainable development.

At present, considering on the natural resource and environmental problems caused by the construction and demolition waste, especially the sintered brick waste (sintered brick construction). Therefore, in order to solve this problem, the researcher have studied how to reuse all type of this waste and recycling materials for civil engineering.Recycled concrete aggregate is a common recycling utilization method of concrete waste. The recycling of AACW aggregates was mainly used for purpose of lightweight. AACW aggregate was used as porous internal curing agent to replace normal aggregate. Autoclaved aerated concrete waste (AACW) iscollected from the construction demolition site to prepare ultrafine particles by wet-milling [24]. The waste brick powder as partial used to replace the amount of cement [25].Recycling aerated concrete blocks (ACB) and sintered clay bricks (SCB) [26].

Recycled brick powder is processed from brick in the construction and demolition waste and used to instead of fine aggregate (quartz sand) have not studied yet by scholars. Therefore, in this research open up for new directions of development recycled micro-powders and also promotes the sustainable development of the construction industry which is great significance for guiding engineering practice.

Since, there is no relevant example of the preparation of PVA-ECC by the mixing of recycled brick powder to replace fine aggregate (quartz sand), this paper combines the preparation of recycled brick powder with PVA-ECC technology to produce a hardening-strain effect with strength up to ordinary ecological ultra-high toughness cement-based composite material (ECO-ECC) of high-strength concrete is more economical and environmental friendly than the traditional ECC. Through the relevant experimental research, the ECO-ECC material prepared by this group is verified to have good ductility and high toughness, the modification of recycled micro-powder and low temperature test are carried out.

1.3 The main work of the article

The ECO-ECC is a new type of ecological ultra-high toughness cement-based composite material (ECC). It was used recycled brick powder (RBP) to replace fine aggregate (quartz sand). The using of RBP which not only ensures to reduce the construction costs but also realizes the recycling and reuse of the construction waste in our country, especially, reduce the using of natural resource and reduce the harm of construction waste to the environment.

In this paper, we mainly study the on the high ductility, high toughness, the number of maximum width crack, load-deflection cure, flexural strength and compressive strength of the specimen with the different replacement amount of recycled brick powder and the variation of cold regime temperature curing. The experiment test was described at the below:

1) Flexural strength test curve was obtained
2) Compressive strength test curve was obtained
3) Four-point bending-load deflection test curve was obtained
4) The recycled brick powder replacement amount
a. Recycled brick powder 25% was used to instead of quartz sand
b. Recycled brick powder 50% was used to instead of quartz sand
c. Recycled brick powder 75% was used to instead of quartz sand
d. Recycled brick powder 100% was used to instead of quartz sand
5) Curing at variation cold regime temperature
a. Curing at cold regime temperature 0°C
b. Curing at cold regime temperature -10°C
c. Curing at cold regime temperature -20°C
d. Curing at cold regime temperature -30

II. MATERIALS AND EXPERIMENTAL STUDY

2.1 Raw materials

Inthis experiment research, we used many kinds of raw materials for the preparation of ecological engineering cementitious composite (ECO-ECC), the experiment materials are mainly cement, fly ash,water, polyvinyl alcohol fiber (PVA fiber), admixture (see in Fig. 2) and recycled brick powder(see in Fig. 2below). For using of material, we just focus only two types of materials. The first one is PVA fiber and the second is recycled brick powder. In the ecological engineered cementitious composites (ECO-ECC) matrix comprised: P.O 42.5 ordinary Portland cement, fine aggregate, fly ash, recycled brick break, high rang water reduce admixture (HRWRA), thickener and PVA fiber. The PVA fiber used 1.75% by mass and recycledbrick powder particlesize less than 75µm used 4.25% ,75µm-125 µm used 20.67% , 125µm -150µm used 34.92%, 150µm -200µm used 39.72%, and 200µm -300µm used 0.44% by mass.

Fig. 1Recycled Brick Powder

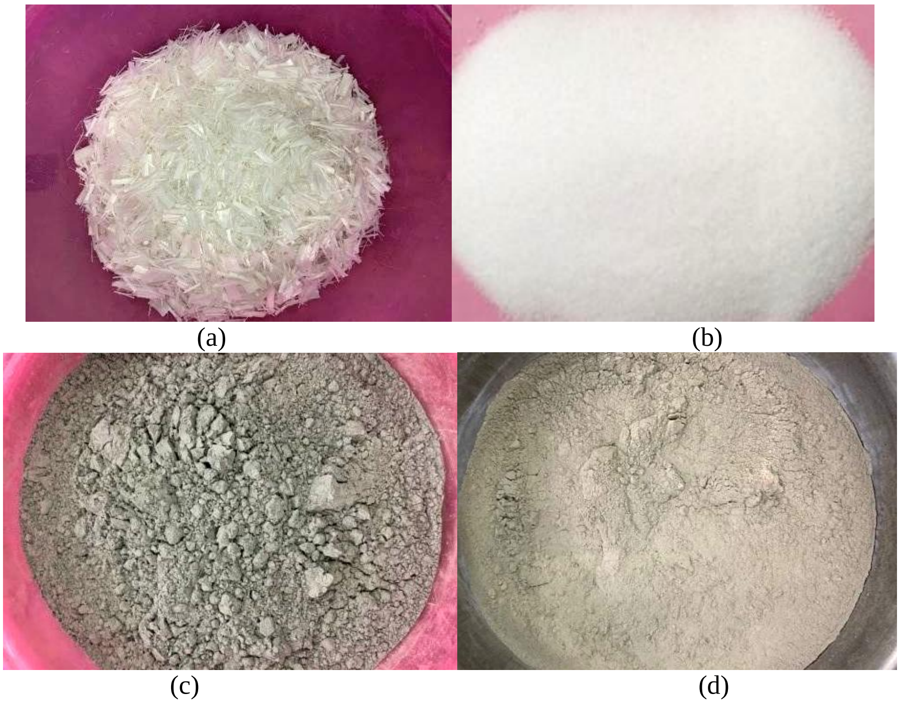

(a) (b)
(c) (d)

Fig. 2. Raw materials: (a). PVA fiber, (b). Quartz sand, (d). Cement, (d). Fly ash

2.2 Materials and preparation of specimens

2.2.1 Cement

Cement is the most important materials were used for preparing ECO-ECC. In mix design, we used P.O 42.5 ordinary Portland cement which produced by Henan Sheng Xingyang City. Cement is a main material that we always use for make the specimen, and it also play in an important role in strength of the structure. The chemical composite of ordinary Portland cement shown in Table 1 below:

Table. 1 Mechanical Properties of Cement

Ingredient of Cement	Al2O3	SiO3	CaO	Fe2O3	MgO	R2O	SO3	Loss
Content (%)	5.47	21.08	62.28	3.96	1.73	0.5	2.63	1.61

2.2.2 Fly ash

Used first-class fly ash for mix design and it provided by Tianjin Yangliuqing Powder Plant. Fly ash is a material like dust that we were collected from the flue of coal-fired thermal power plants with a vacuum and also get if from the industrial waste. The particle size of fly as used in the test is 300 mesh (see Table 2). There are also some of chemical reaction with calcium hydroxide or other alkaline earth metal hydroxides to generate the compounds with hydraulic gelling properties. It also is the material that increase strength and ductility and it is commonly used as an admixture of concrete, reduce the amount of cement, reduce water consumption, bleeding rate, reduce heating of hydration, and thermal expansion. The chemical composite shown in Table 2 below:

Table. 2 Chemical composite of Fly Ash

Ingredient of fly ash	SiO_2	MgO	Fe_2O_3	Na_2O	Al_2O_3	CaO
Content (%)	53.97	1.01	4.16	0.89	31.15	4.01

2.2.3 Water

The ordinary drinking water, and use the requirement of concrete mixing water standard JGJ63-89.

2.2.4 PVA fiber

There are so many types of admixture that they usually use for the construction site and for doing some experiments, but in this test, we used only two type of admixture for all specimens; High Rang Water Reduce Admixture (HRWRA) and Thickener, all this products were provided by Shanghai Chenqi Chemical Technology Co., Ltd.

2.2.5 Recycled brick powder

In this experiment, used recycled brick powder or we called recycled material that were used to replace and instead of fine aggregate (quartz sand) by mass to prepare ECO-ECC. Recycled brick powder is made by waste of sintered brick construction in urban by ZhengdaGongtu Testing Company. First, the sintered brick waste is crushed by the crushing machine (see in Fig. 3a), then use the standard screening machine (see in Fig. 3b) for control the particles size of it. The 75µm-200 µm particle size of recycled brick powder used in this experiment is displayed in Table 3. This material also can collect from construction and demolition waste and red brick waste in China. Then we used the breaking machine for break it to become like dust, and then we used screening machine to control the particle size.

Table. 3. Particle size distribution of recycled brick powder

Size (µm)	<75	75-125	125-150	150-200	200-300
Contain (%)	4.25	20.67	34.92	39.72	0.44

2.2.6 Fine aggregate (quartz sand)

Quartz sand (see in Fig.5b) were used in the experiment provided by Henan Zhongbang Environmental Protection Technology Co., Ltd.The particle size from 75 µm to 200 µm.

(a) (b)

Fig. 3.Crushing and screening machine: (a). Crushing machine; (b). Screening machine

2.2.7 Specimen preparation

In this experiment, the ECC and ECO-ECC that contained brick-power was mixed by using shaft mixer (see in Fig. 4a). For the first is dry mix, we placed cement, fly ash and quartz sand or brick powder into shaft mixer and then mix it for 2 min. After that, high rang water reduce admixture (HRWRA) and water were added and stirred for 2 min. Finally, PVA fiber was added slowly into mixer for 1 min and then thickener was added and mixed for 2 min. After all step of mixing were completed, we need to check, are there any that have not been fully stirred at side and bottom of barrel then mixed with the fast rotate of mixer for 4 min.

For casting ECC ECO-ECC, we were divided into two types of steel mold, used prism specimen of $160\text{mm}\times40\text{mm}\times40\text{mm}$ steel mold for flexure strength and compressive strength test and used rectangular thin plat samples measuring $320\text{mm}\times100\text{mm}\times10\text{mm}$ steel mold for bending behavior. In the processing of molding, the fresh Engineered Cementitious Composite (ECC) and ecological engineering cementitious composite (ECO-ECC) were cast in molds then compact it by used a vibration table as shown in Fig. 4b for 30s, and then covered it with the plastic film as we shown in Fig. 5(in order to avoid the evaporation) for 24h in room temperature. After 24h, the specimens were demolded and cured it in cold machine (see in Fig. 6), the temperature was conducted are $0^{o}C$, $-10^{o}C$, $-20^{o}C$, $-30^{o}C$ for 7 days until testing date.Note: need to take it out from the cold machine and cured it in room temperature for 8h before test.

(a) (b)

Fig. 4. Shaft mixer and vibration table: (a). shaft mixer, (b). vibration table

Fig. 5. Photo of covered with plastic film

Fig. 6. Cold machine

2.3 Procedure and Testing Method

2.3.1 Compressive test set up

The compression machine (see in Fig. 7b) used to define the compressive strength of each specimens. The compressive strength of ECC and ECO-ECC specimens were tested by using the compression machine according toGB/T17671-1999 (Inspection method of cement mortar strength), model YAW-300C with the specific capacities 100kN. The specimen's dimension was 40mm (width) 40mm (high) and 160mm (long), we also used the automatic testing machine under the loading rate 2.4 kN/s control by EHC-2300 automatic pressure testing machine. The compressive strength $(f_c^{'})$ was calculated by the equation (1)

$$f_c^{'} = \frac{P}{A} \qquad (1)$$

- P: axial load (kN)
- A: cross section area (mm^2)

2.3.2 Flexural test set up

The flexural strength of ECC and ECO-ECC sample was applied by using the three-point bending test and controlled by EHC-2300 automatic machine according to GB/T17671-1999 (Inspection method of cement mortar strength), model YAW-300C with the specific capacities 100kN (see in Fig. 7a). The beam specimens were used the dimension of 40mm (width) 40mm (high) and 160mm (long).The ECC beam specimens were performed by using EHC-2300-fold machine with a constant loading rate 50N/s in order to analysis the flexural strength of beam specimens andflexural strength (f_f) was calculated by equation (2):

$$f_f = \frac{1.5P \times L}{b^3} \quad (2)$$

– P: loading at mid-span (N)
– L: specimen's length (mm)
– b: width of the specimen (mm)
– f_f : flexural strength (MPa)

2.3.3 Bending test set up

In order to analyze the bending behavior of beam specimens, we used the Four-Point Bending test and conducted by using electronic universal testing machine (see in Fig. 7c), model WDW-100, capacity 100kN with a rectangular thin plat sample measuring 320mm (length) 100mm (width) 10mm (thickness). The Auto-Graph machine used for the bending test and used LVDTs to determine the displacement ofbeam's specimens with the displacement rate 0.2mm/min .

(a) (b) (c)

Fig. 7. Testing machine photo: (a). Flexural test, (b). Compressive test, (c). Bending test

2.4 Ratio of mix design and water requirement

2.4.1 Mix ratio

In generally, the researcher always creates their own ratio for doing the experiment research. In this test, we used the test ratio into two types. The first one is based on the mix replacement the amount of recycled brick powder (%). Second, is based on the mix ratio of raw materials, fly ash-fly ash cement mass ratio FA/(FA+C) = 0.35,quartz sand or recycled brick powder-fly ash cement ratio mass S or RBP/(FA+C) = 0.35, water-fly ash cement mass ratio W/(FA+C) = 0.35, high rang water reduce admixture-fly ash cement mass ratio HRWR/(FA+C) = 0.0015 and thickener-fly ash cement mass ratio Thickener/(FA+C) = 0.0015. The benchmark mix ratios are shown in Table 4.

Table. 4 Benchmark mix ratios (kg/m^3)

– Water additional condition when added the recycled brick powder

Group	C	W	FA	S	RBP Replacement (%)	PVA fiber	Thickener	HRWR
ECC-NC	770	415	415	415	0	22.75	0.6	0.6
ECC-RBP1	770	415	415	415	25	22.75	0.6	0.6
ECC-RBP2	770	415	415	415	50	22.75	0.6	0.6
ECC-RBP3	770	415	415	415	75	22.75	0.6	0.6
ECC-RBP4	770	415	415	415	100	22.75	0.6	0.6

Water added= (water requirement test/ additional water rate) × amount of replacement
Water requirement test = 430, Additional water rate = 1350

2.4.2 Fluidity of recycled brick powder

The recycled brick powder absorption is greater than natural fine aggregates (quartz sand), the water absorption rate will reduce the fluidity of fresh concrete [27]. We used natural sand to evaluate the water absorption index as the basis for its grade. Used table jumping test or cement mortar fluidity tester (see in Fig. 8) and the slurry consistency test are currently standard test method for judging the fluidity of the cement mortar in many countries in the world [28]. In this test, the jumping table test was used to measure and characterize the flow performance of recycled brick powder sand and theflow ration. The recycled brick powder sand flow ratio was prepared with recycled brick powder and sand with the additional water require for the regenerated fine powder with different qualities was evaluated through the water consumption index test of recycled brick powder sand flow ratio. The measurement method is following as the below:

(1) The weigh 1350g of standard sand and 540g of benchmark cement and added appropriate amount of water to make benchmark mortar was tested the fluidity of mortar according to the method specified in GB/T2419.

(2) Weigh the recycled brick powder, recycled brick powder 1350g and benchmark cement 540g, then added the appropriate amount of water to make reclaimed mortar and test the mortar fluidity of regenerated brick powder according to specification by adjusting the water consumption, the fluidity is made to be consistent with the reference mortar and water corresponding consumption or the water demand. The test result is shown in the Table 5below

Table. 3 Water demand of recycled brick powder flow ratio

Category	Fluidity (mm)	Water consumption (g)
Mortar benchmark	210	230
Recycled brick powder with sand	210	660

Fig. 8. Cement mortar fluidity tester

III. RESULT AND DISCUSSION

3.1 Flexural test

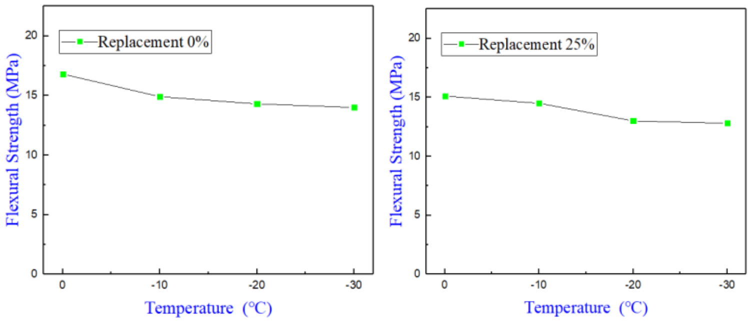
3.1.1 Effect of temperature on flexural strength and recycled brick powder amount

After we finished doing experiment, the result was shown in the describe below. In the result,shown the average flexural strength (f_f) of the specimen with difference temperature and difference of recycled brick powder replacement amount to instead of fine aggregate (quartz sand) of engineered cementitious composite (ECC) and ecological engineering cementitious composite (ECO-ECO) at curing time 7 days and it was shown inTable 6below.

In this experiment, we divided into five groups. It was divided depend on the replacement amount of recycled brick powder: named ECC-NC is non-replacement and cured in cold regime temperature are $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$; ECC-RBP1 is 25% replacement amount and cured in cold regime temperature are $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$; ECC-RBP2 is 50% replacement amount and cured in cold regime temperature are $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$; ECC-RBP3 is 75% replacement amount and cured in $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$; ECC-RBP4 is 100% replacement amount and cured in cold regime temperature are $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$ respectively, as shown in Table 6. This point, the result shown the specimen's strength with different temperature and at curing time (t) 7 days. The temperature has potential for effecting on the flexural strengthwhentemperature decreased from $0^{\circ}C$ to $-30^{\circ}C$, the flexural strength of the matrix also decreased, as shown in Table 6. It can be seen that for the non-additional recycled brick powder (ECC-NC) of the quartz sand with the difference temperature, the flexural strength of ECC-NC decreased by 8.9%, 5.2%, 6.9% as shown in Fig. 9a. When the additional of recycled brick powder by mass increased to 25% for group ECC-RBP1, the flexural strength of it also decreased by 4%, 9%, 3% as shown in Fig. 9b. And the addition of recycled brick powder by mass increased to 50% for group ECC-RBP2, the flexural strength decreased by 3.4%, 8.6% and 4.7% (see in Fig. 10a). For the additional of the recycled brick powder by mass increased to 75% with the variation of temperature $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$, the flexural strength decreased by 2.3%, 1.6% and 4.8% (see in Fig. 10b). The last one is the additional of recycled brick powder by mass increased to 100% with the variation of temperature are $0^{\circ}C, -10^{\circ}C, -20^{\circ}C, -30^{\circ}C$, the flexural strength also decreased by 5.5%, 4.2% and 4.3% as shown in Fig. 11a. The flexural strength comparison of each replacement amount with the variation of temperature are shown in Fig. 11b.

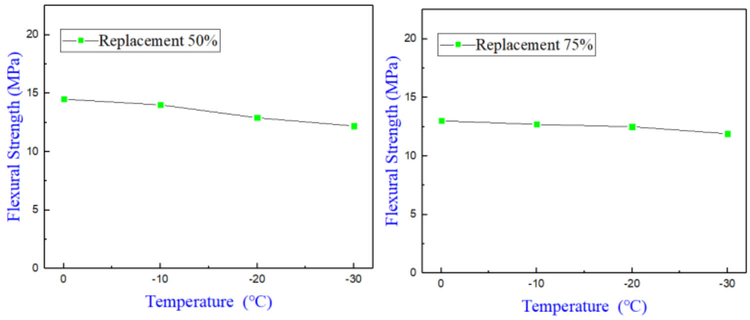
Table. 6. The average flexural strength (MPa)

Temperature Group	**Flexural Strength (MPa)**			
	0 ℃	-10 ℃	-20℃	-30℃
ECC-NC	16.8	14.9	14.3	14
ECC-RBP1	15.1	14.5	13	12.8
ECC-RBP2	14.5	14	12.9	12.2
ECC-RBP3	13	12.7	12.5	11.9
ECC-RBP4	12.7	12	11.8	11.2



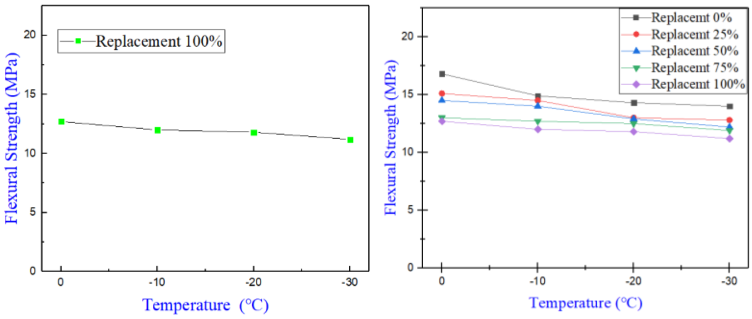
(a) (b)

Fig. 9.Effect of temperature on flexural strength; (a). non-replacement; (b). replacement 25%



(a) (b)

Fig. 10.Effect of temperature on flexural strength; (a). replecement 50%; (b). replacement 75%



(a) (b)

Fig. 11. Effect of temperature on flexural strength; (a) replacement 100%; (b), replaced 0% -100%

3.2 Compression test

3.2.1 Effect of temperature and recycled brick powder amount on compressive strength

The uniaxial compressive strength and deformation of concrete materials are its most basic on mechanical properties which is to study of the concrete structure. The mainly basic of bearing capacity and deformation of the concrete structure. The cube compressive strength test is the basis for dividing the concrete strength grades. The compressive test of the piece was carried out to focus the effect of the variation of cold regime temperature and the replacement amount of recycled brick powder on the compressive strength of the self-compacting. In order to study the effect of variation cold regime temperature and recycled brick powder content on self-compacting of group ECC-NC, ECC-RBP1, ECC-RBP2, ECC-RBP2 and ECC-RBP3 compressive strength was conducted according to GB/T17571-1999 (Cement mortar strength inspection method, it is iOS method). We take the two broken blocks after the end of the flexural test for making compressive test. A total of 48 pieces which don't have recycled brick powder content were cured in cold regime temperature 0°C, -10°C, -20°C and -30°C for 7 days (ECC-NC), 48 pieces that have recycled brick powder content 25% were cured in cold regime temperature 0°C, -10°C, -20°C and -30°C for 7 days (ECC-RBP1), 48 pieces that have recycled brick powder content 50% were cured in cold regime temperature 0°C, -10°C, -20°C and -30°C for 7 days (ECC-RBP2), 48 pieces which have recycled brick powder content 75% were cured in cold regime temperature 0°C, -10°C, -20°C and -30°C for 7 days (ECC-RBP3), 48 pieces that have recycled brick powder content 100% were cured in cold regime temperature 0°C, -10°C, -20°C and -30°C for 7 days (ECC-RBP4). We need to dry the piece for 8h before test. The average compressive strength ($f_c^{'}$) of the all the specimens are shown in Table 7 above. The compressive strength result shown that, when the ECC-NC cured in 0°C, -10°C, -20°C and -30°C for 7 days, the compressive strength value of the piece are 22.4 MPa, 21.2 MPa, 19.8 MPa and 18 MPa (see in Fig.12); when the ECC-RBP1 cured in 0°C, -10°C, -20°C and -30°C for 7 days, the compressive strength value of the piece are 21 MPa, 18.6 MPa, 17.9 MPa and 17.3 MPa (see in Fig.13); when the ECC-RBP2 cured in0°C, -10°C, -20°C and -30°C for 7 days, the compressive strength value of the piece are 20 MPa, 18 MPa, 16.5 MPa and 16.2 MPa (see in Fig.14); when the ECC-RBP3 cured in 0°C, -10°C, -20°C and -30°C for 7 days, the compressive strength value of the piece are 19.5 MPa,16.6 MPa, 15.6 MPa and 15 MPa (see in Fig.15); when the ECC-RBP4 cured in 0°C, -10°C, -20°C and -30°C for 7 days, the compressive strength value of the piece are 18.2 MPa, 15.4 MPa, 14.8 MPa and 14 MPa (see in Fig.16). Thus, the variation of temperature is affected to the compressive strength of the sample, when the temperature decreased from 0°C to -30°C the compressive strength also decreased significantly. Moreover, the recycled brick powder replacement amount also effected to the compressive strength of the specimen, we can be seen that the increasing the of recycled brick powder replacement content by mass, the compressive strength decreased significantly. The comparison of average compressive strength for the variation of the recycled brick powder replacement amount with the difference of cold regime temperature are shown in Fig. 17below.

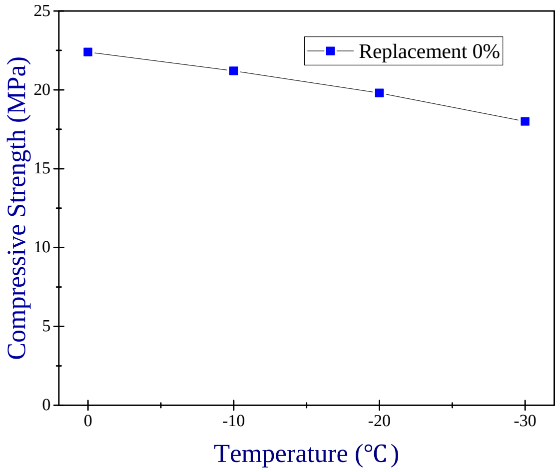


Fig. 12. The average compressive strength for non-replacement, variation of temperature

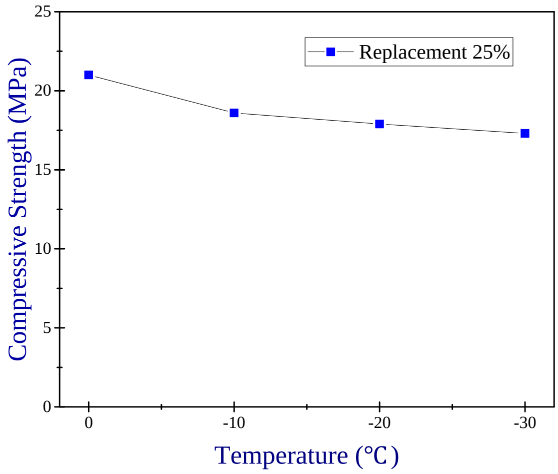


Fig. 13. The average compressive strength for replacement 25%, variation of temperature

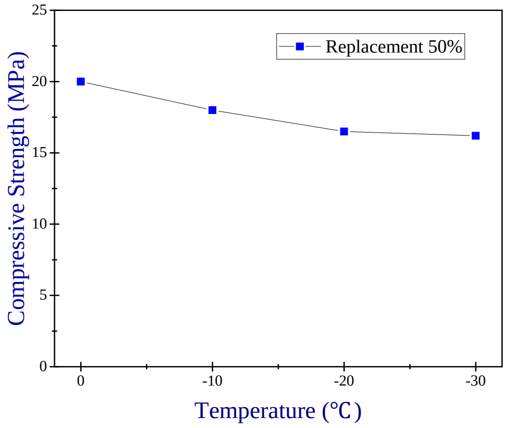


Fig. 14. The average compressive strength for replacement 50%, variation of temperature

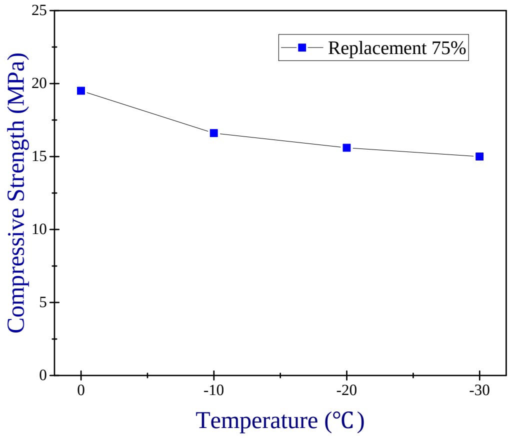


Fig. 15.The average compressive strength for replacement 75%, variation of temperature

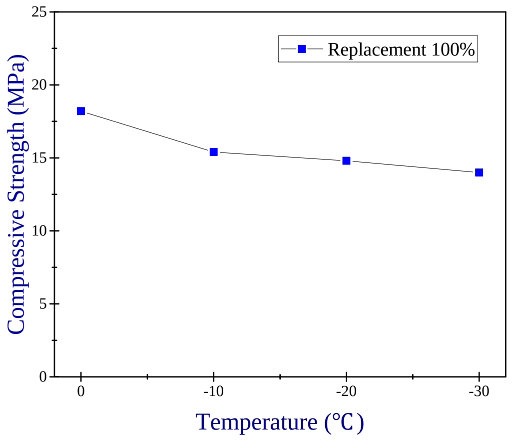


Fig. 16.The average compressive strength for replacement 100%, variation of temperature

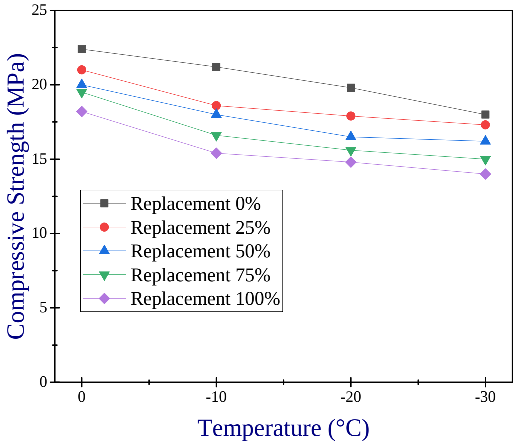


Fig. 17.Comparison of average compressive strength; variation of temperature with differencereplacement amount of recycled brick powder

3.3 Bending toughness behavior and analysis

3.3.1 Effect of temperature and recycled brick powder amount on compressive strength

In figures below will present about the flexural behavior and flexural load midspan deflection curves of specimens group ECC-NC, ECC-RBP1, ECC-RBP2, ECC-RBP3 and ECC-RBP4 with the variation cold regime temperature (0°C, -10°C, -20°C, -30°C) and difference replacement amount of recycled brick powder by mass are 25%, 50%, 75% and 100% cured for 7 days. In the beginning of loading, the specimen is in the elastic stage, and no cracks appear on the lower surface of the specimen. After the elastic stage have gone, the first creak appears in the section subjected to the bending load. Due to the increasing of bending load, since the load bearing capacity of PVA fiber is much greater than the matrix material, so the fiber play in an important role, and the load gradually rises at the certain value, a second crack begins to appear and the number of cracks continues to increase. After that, the load limit is about to be reached, one the cracks expand faster and becomes larger and larger until it can no longer bear to the load and local damage. Soon, the ultimate load is reached, a large number of fibers pulled out at the bottom of the specimen. Through the observation of the test process, all the cracks appeared due to the bending load action, the spacing of all cracks are basically equal, especially, the crack before failure like a micro-crack. The bending load deflection curves are shown in the Fig. 18, 19, 20, 21 and Fig. 22below:

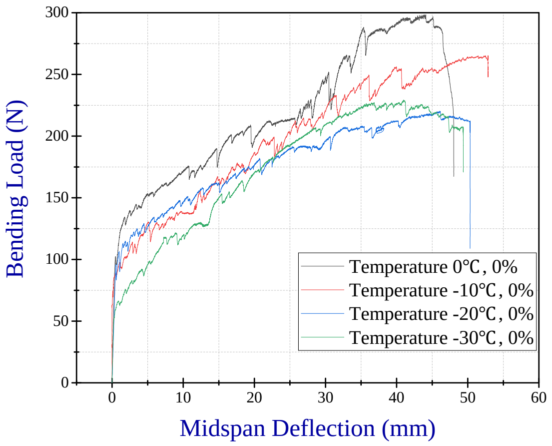


Fig. 18.Load-deflection of (ECC-NC): the replacement amount 0%, variation of temperature

Observe on Fig. 18, it is not difficult to find the and describe the load mid-span deflection curve: in this test, we did not use recycled brick powder to replace the fine aggregate (quartz sand) and then cured it in the cold temperature 0°C, -10°C, -20°C and -30°C, the slop of the elastic stage in the load-deflection curve decrease as we decrease temperature and the ultimate bending load also decreases when temperature decreased. At 0°C the ultimate bending load about 300N and maybe about 200N at -30°C. When the temperature decreased from 0°C, -10°C, -20°C, -30°C the number of micro-cracks is less but the width of crack is larger than before. It shown that the toughness index is also decreased with the decreasing of temperature. Although the temperature is different, but there is no difference in mid-span deflection.

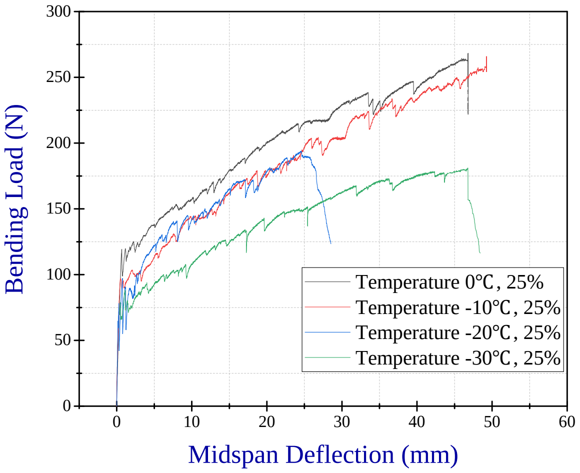


Fig. 19. Load-deflection of ECC-RBP1: replacement amount 25%, variation of temperature

For the Fig. 19, 21, andFig.22 the ECO-ECC combined with the amount of recycled brick powder are 25%, 75% and 100% to replace fine aggregate (quartz sand) were curved with the decreasing of temperature from 0°C, -10°C, -20°C and -30°C: the result shown that the slope of elastic phase in the load-deflection curve decreases when the temperature decreased with the increasing of recycled brick powder amount. The increasing of recycled brick powder, the stiffness of the specimen body decreases and the matrix strength of the ECO-ECC also decreased. At the same time, the bending load also decrease and mid-span deflection decreases. As the amount of recycled brick powder increases and temperature decreases, the toughness index decreases.

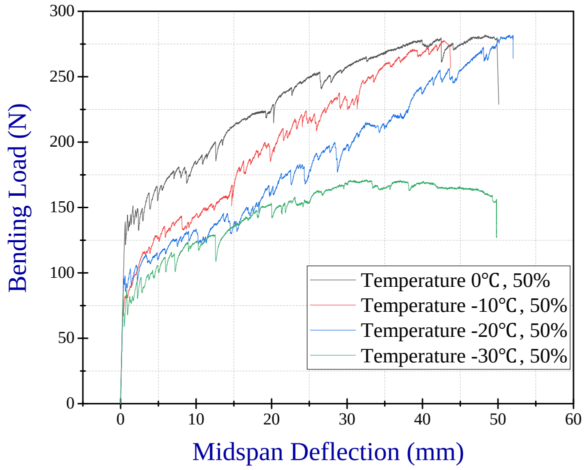


Fig. 20. Load-deflection of ECC-RBP2: replacement amount 50%, variation of temperature

For Fig. 20the recycled brick powder content 50% and temperature are decreased from 0°C, -10°C, -20°C and -30°C, the slope of the elastic phase in the load-deflection curve decreases, the base stiffness of the body also decrease, the matrix strength of ECO-ECC also decrease.

Although the amount of RBP is different but there is no difference in mid-span deflection. As you see in the fig. below, the RBP 50% and quartz sand 50% with the decreasing of temperature, the number of cracks is increased, but the width of crack is smaller than when we cured at 0°C.

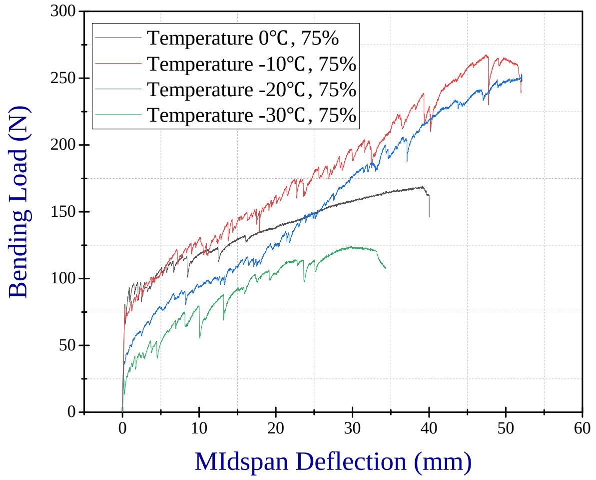


Fig. 21.Load-deflection of ECC-RBP3: replacement amount 75%, variation of temperature

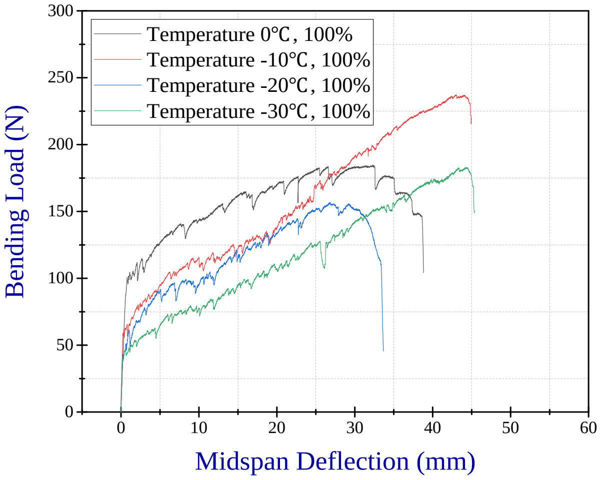
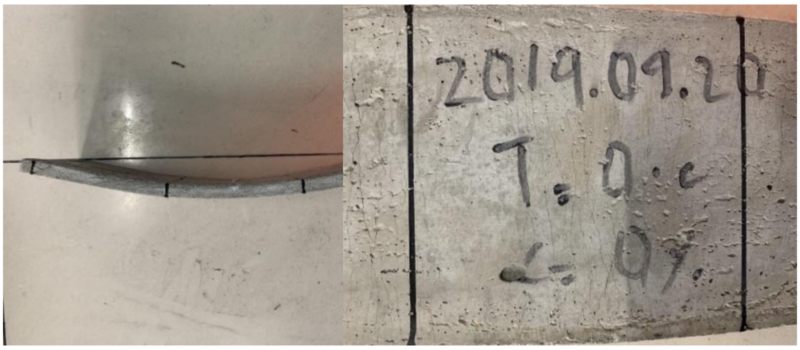


Fig. 22.Load-deflection of ECC-RBP4: replacement amount 100%, variation of temperature

3.3.2 Failure mode of bending test specimens at variation temperature with different replacement amount of RBP as quartz sand

For all specimens were cured at different temperature at cold regime temperature are 0 °C, -10°C, -20°C and -30°C with the variation replacement amount of recycled brick powder as quartz sand are 25%, 50%, 75%, and 100%, respectively. The Fig. 23below is shown each four-point bending photo for side deflection of the specimen and bottom micro-cracks of the specimen under different proportion. The deflection of each specimen has greater and greater under loading performance and some of specimens, the deflection has decreased after unloading (the elastic-plastic phase). The two solid black line is theloading point on each specimen.

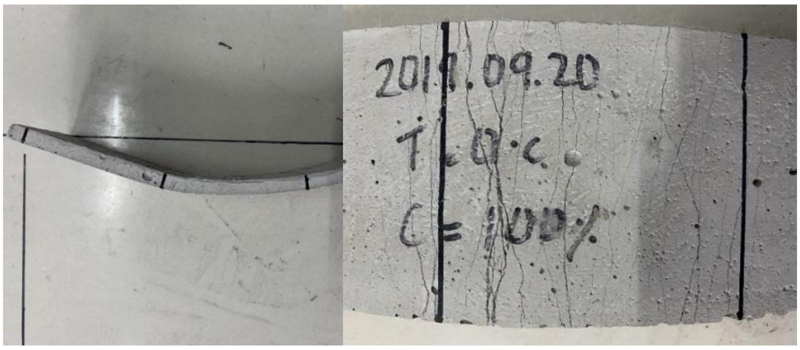


ECC-NC: Recycled brick powder 0%, Quartz sand 100%, Temperature 0°C

ECC-RBP1: Recycled brick powder 25%, Quartz sand 75%, Temperature 0°C

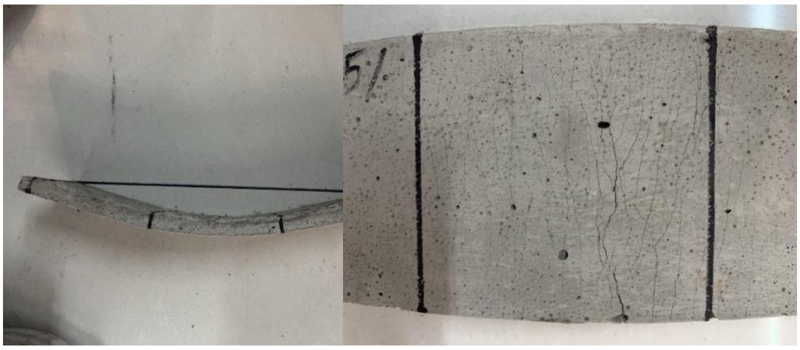
ECC-RBP2: Recycled brick powder 50%, Quartz sand 50%, Temperature 0°C

ECC-RBP3: Recycled brick powder 75%, Quartz sand 25%, Temperature 0°C



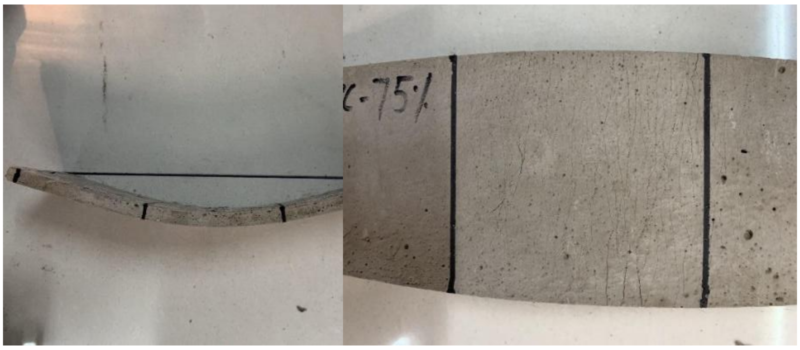
ECC-RBP4: Recycled brick powder 100%, Quartz sand 0%, Temperature 0°C

ECC-NC: Recycled brick powder 0%, Quartz sand 100%, Temperature -10°C



ECC-RBP1: Recycled brick powder 25%, Quartz sand 75%, Temperature -10°C

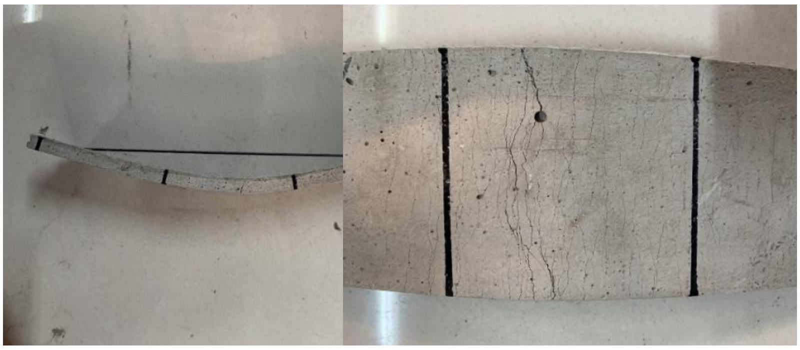
ECC-RBP2: Recycled brick powder 50%, Quartz sand 50%, Temperature -10°C



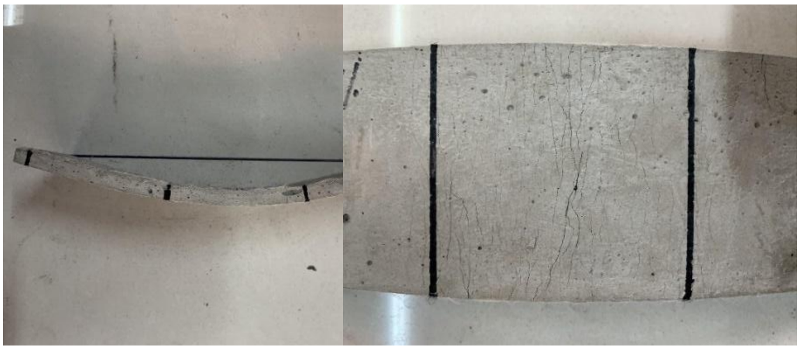
ECC-RBP3: Recycled brick powder 75%, Quartz sand 25%, Temperature -10°C

ECC-RBP3: Recycled brick powder 100%, Quartz sand 0%, Temperature -10°C

ECC-NC: Recycled brick powder 0%, Quartz sand 100%, Temperature -20°C



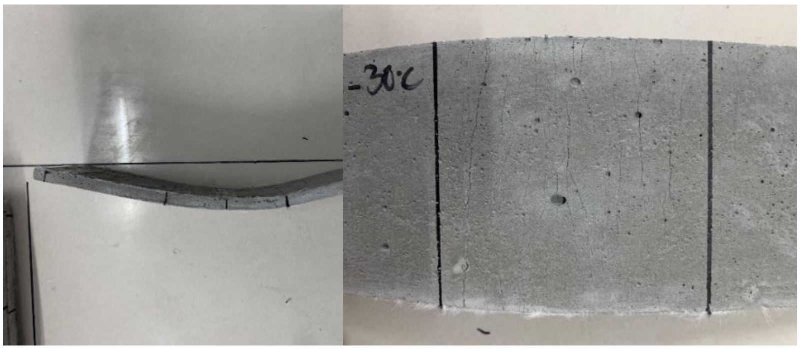
ECC-RBP1: Recycled brick powder 25%, Quartz sand 75%, Temperature -20°C



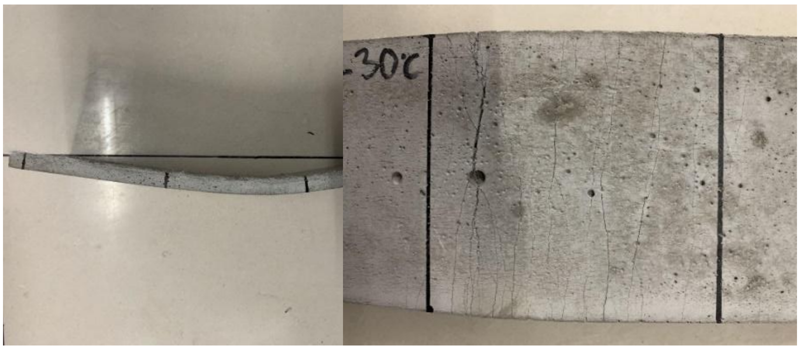
ECC-RBP2: Recycled brick powder 50%, Quartz sand 50%, Temperature -20°C

ECC-RBP3: Recycled brick powder 75%, Quartz sand 25%, Temperature -20°C

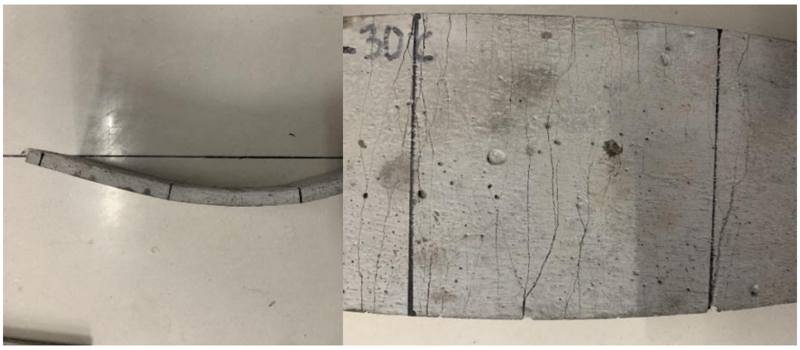
ECC-RBP4: Recycled brick powder 100%, Quartz sand 0%, Temperature -20°C



ECC-NC: Recycled brick powder 0%, Quartz sand 100%, Temperature -30°C

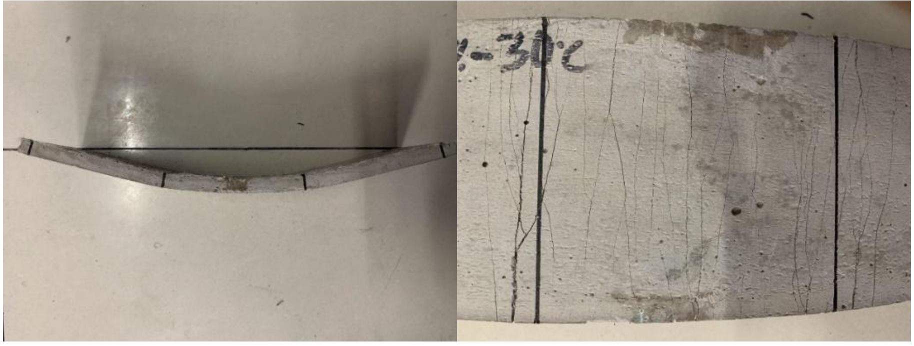


ECC-RBP1: Recycled brick powder 25%, Quartz sand 75%, Temperature -30°C



ECC-RBP2: Recycled brick powder 50%, Quartz sand 50%, Temperature -30°C

ECC-RBP3: Recycled brick powder 75%, Quartz sand 25%, Temperature -30°C



ECC-RBP1: Recycled brick powder 100%, Quartz sand 0%, Temperature -30°C

Fig. 23. Photo of side deflection and bottom crack of the specimen

For the figure above, it can be seen that all specimens do not have matter whenever we used brick concrete mixes with different amounts of quartz sand, different recycled brick powder with variation of temperature at the same substitution rate, the number of cracks if multi-crack development after load was conducted, and the maximum mid-span deflection is more than 35mm until 45mm. Therefore, the ECO-ECC has ultra-high toughness and the hardening strain characteristics that we can use it for civil engineer.

IV. CONCLUSION AND OUTLOOK

4.1 Conclusion

There are many researchers research about Engineered Cementitious Composite (ECC) as the construction material and now ECC is also popular for civil engineering around the world. Nowadays, our team have been researching about ecological engineered cementitious composite (ECO-ECC) and it is also the new type of construction material as we have known that it is an ecological ultra-high toughness cement-based composite material. In this studied, we used construction waste (brick block) to replace fine aggregate (quartz sand) and used PVA fiber 1.7% for making ECO-ECC. The using of construction waste (brick block) which not only reduces costs but also realizes the construction waste and landfilled etc. Moreover, reusing of construction waste as the natural materials are reducing harmful to the environment. In this paper, we studied about the basic mechanical properties of ecological of engineered cementitious composite (ECO-ECC) under different cold regime temperature of different substitution of recycled brick powder. The flexural strength, compressive strength and four-point bending toughness characteristics of ECO-ECC were studies.

In order to study the influence of the temperature and recycled brick powder factors on the performance of ECO-ECC is completed on the basic of the superior substitution amount was obtained by the test and the proportion of recycled brick powder to satisfying ultra-high toughness. In this test is mainly focus on the mechanical properties and working performance of ECO-ECC, as we shown in the summarize conclusions below:

（1） Using recycled brick powder to instead of fine aggregate (quartz sand), the ECO-ECC also have high toughness, the strength nearly can reach the strength of ordinary high-strength concrete. The bending span deflection is good toughness and ductility, also can reach between about 35mm to 45mm.

（2） The compressive strength of the ECO-ECC specimen block was decreased when the recycled brick powder content from 25%, 50%, 75%, 100% to instead fine aggregate (quartz sand) with the constant of temperature 0°C and compressive strength also decrease when temperature decreased from 0°C, -10°C, -20°C and -30°C. The flexural strength characteristic also performs like the compressive strength, it's also deceased when the recycled brick powder increased with the decreasing of temperature.

（3） When using recycled brick powder to replace quartz sand increased, the flexural span deflection of the ECO-ECC are decreased and the but not too much, it is decreased about 15% when the replace amount increase until 100%. The bending load deflection also can be found from the curve that as the increasing of the recycled brick powder, the cracking strength with the ultimate deflection also gradually decrease as the curve above but the milt-cracking are increased.

4.2 Outlook

In this paper, our experimental were studied on the mechanical properties of Ecological Engineered Cementitious Composite (ECO-ECC) which content Recycled Brick Powder and PVA fiber after expose to low temperature during the master's degree is limited. It is limited to experimental conditions and personal energy, time and other reasons. The article only conducts some mechanical properties of ECO-ECC which made by recycled brick powder to replace quartz sand. About research and analysis, there are still many difficulties to be solved in the test. To further prepare more optimized ECO-ECC materials and better apply it to the actual projects, through this phase test and reading of related literature, it is found that there is still need to be further in the future more excellent as the follows:

(1) Loading rate

In the test found that the loading rate has a significant effect on the basic mechanical properties of ECO-ECC. The use of an appropriate loading rate is conducive to exerting the bending toughness characteristics. In order to apply it to actual engineering, it is necessary to further study about the loading rate. Then need to find out the ECO-ECC loading rate that is more realistic and has good performance.

(2) Deeply study of the durability of ECO-ECC made by recycled brick powder to instead of fine aggregate (quartz sand)

Relevant experimental studies have found that the combination of ECC and brick powder improves the defects if compared to the ordinary concrete, such as high brittleness, and ECC has been used as a repair material in engineering to improve the durability and strength of the structure. At the present, there are a few researchers have been researching about the durability of ECO-ECC which made by recycled micro-powder to instead of fine aggregate (quartz sand). Especially, there is no research on the durability performance of ECO-ECC which prepared by using recycled brick powder to instead of quartz sand. Thus, researcher should be strengthened research on the durability and other mechanical properties that we have not researched of ECO-ECC and developed, provide reference value for the future application of materials in civil engineering.

(3) The addition of admixture

In this experiment, it was found that the admixture also has a significant on the mechanical properties of ECO-ECC, further experiments are needed to find the amount of high range water reduce admixture and thickener that make ECO-ECC have the best performance during the testing and actual project.

REFERENCE

[1]. Mindess S, Young F, Darwin D. Concrete. 2nd ed. Prentice Hall; 2003.

[2]. Wu Honglei, Luo Min, Pan Jinlong. Effect of different construction measures on temperature stress distribution of ultra-long reinforced concrete frame factory building (J). Jiangsu Construction, 200943(9): 28-31.

[3]. Samir N. Shoukry [a], Gergis W. William [b,*], Brian Downie[a], Mourad Y. Riad[b]. Effect of moisture and temperature on the mechanical properties of concrete. Constr. Build. Mater. (2010)

[4]. Naus DJ, Graves HL. A review of the effects of elevated temperature on concrete materials and structures. In: Proceedings of the 14th International Conference on Nuclear Engineering, ASME, Miami, Florida, USA; 2006.

[5]. Korhonen CJ, Orchino SA. Off-the-shelf antifreeze admixture for concrete. Final Report ERDC/CRREL TR-01–2, US. Army Engineer Research and Development Center: Hanover, New Hampshire, USA; 2001.

[6]. Korhonen CJ. Extending the season for concrete construction and repair: phase ii-defining engineering parameters. Final Report ERDC/CRREL TR-06–8,

[7]. D.R. Gardner [*], R.J. Lark, B. Barr, Effect of conditioning temperature on the strength and permeability of normal- and high-strength concrete, Cem Con Res, 35 (2005) 1400-1406

[8]. PitiSukontasukkul[a,*], WorachetPomchiengpin[a], Smith Songpiriyakij[b]. Post-crack (or post-peak) flexural response and toughness of fiber reinforced concrete after exposure to high temperature

[9]. Zuanfeng Pan [a,*], Chang Wu[b], Jianzhong Liu [c], Wei Wang [b], Jiwei Liu [b], Study on mechanical properties of cost effective polyvinyl alcohol engineered cementitious composites (PVA-ECC). Constr. Build. Mater. (2015)

[10]. Zhikun Ding [a], Wenyan Gong [a], Vivian W.Y Tam [a, b, *], I.M Chethana S. Illankoon[b], Conceptual framework for renovation waste management based on renovation waste generation rates in residential buildings. Jou Cle Prod. (2019)

[11]. LI V C. ECC-tailored composites through micromechanical modeling. Fiber Reinforced Concrete: Present and the Future edited by Banthia et al, CSCE[C], Montreal, 1998,64-97.

[12]. LI V C. On engineered cementitious composites (ECC) a review of the material and its applications. Adv Concr Technol, 2003, 1(3): 215-230.

[13]. LI V C, WANG S, WUC. Tensile strain-hardening behavior of PVA-ECC. ACI Mater J, 2001, 98(6): 483-492.

[14]. Chen Ting, Zhan Binggen. Research progress in designing PVA fiber cement-based composite materials. Concrete, 2003(11): 3-6
LIN Z, KANDA T, LI V C.On interface property characterization and performance of fiber reinforced cementitious composites. Concr Sci Eng, RILEm, 1999(1): 173-184.

[15]. JRC European commission, Supporting Environmentally Sound Decisions for Construction and Demolition (C&D) Waste Management - A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA), Publications Office (2011),

[16]. R.A.S.M. Isidoro, Added value of demolition waste. Characterization, safety conditions in its handling and possibilities of use in the manufacture of concrete (Ph.D. thesis), University of Extremadura, Spain, 2013 (in Spanish).

[17]. Mechanical performance evaluation of concrete made with recycled ceramic coarse aggregates from industrial brick waste

[18]. Suchithra, Kumar Manoj, V.S. Indu, Study on replacement of coarse aggregate by E-waste in concrete, Int. J. Tech. Res. Appl. 3 (2015) 266–270

[19]. An experimental study of replacing conventional coarse aggregate with E-waste plastic for M40 grade concrete using river sand

[20]. QiongLiu[a], Amardeep Singh[a], JianzhuangXiao[a,*], Biao Lia, Vivian WY Tam[b]. Workability and mechanical properties of mortar containing recycled sand from aerated concrete blocks and sintered clay bricks. Res, Conser, Rec

[21]. Kaminskas, R., Mituzas, J., Kaminskas, A., 2006. The effect of pozzolana on the properties of the finest fraction of separated Portland cement-Part 1. Ceram. Silikaty 50, 15.

[22]. Xiao, J., Li, W., Fan, Y., Huang, X., 2012. An overview of study on recycled aggregate concrete in China (1996–2011). Constr. Build. Mater. 31, 364–383.

[23]. Naceri, A., Hamina, M.C., 2009. Use of waste brick as a partial replacement of cement in mortar. Waste Manag. 29, 2378–2384.

[24]. Xingyang He, Zhengqi Zheng, Jin Yang, Ying Su, Tingwei Wang, BohumírStrnadel. Feasibility of incorporating autoclaved aerated concrete waste for cement replacement in sustainable building materials. Jur, pre-proof (2019)

[25]. Viviana Letelier[a,*], Ester Tarela[a], Giacomo Moriconi[b]. Mechanical properties of concrete with recycled aggregate and waste brick powder as cement replacement. Pro, Eng 171(2017)627-632

[26]. QiongLiu[a], Amardeep Singh[a], JianzhuangXiao[a,*], Biao Li[a], Vivian WY Tam[b]. Workability and mechanical properties of mortar containing recycled sand.

[27]. Song Ruixu, Wan Chaojun, Wang Chong, Liu Ning. Experimental research on high strength recycled aggregate and recycled high performance concrete [J]. Concrete, 2003(02): 29-31.

[28]. Tan Minglun, Sun Renjuan, Zhou Zhidong, Zhu Xiuhai, Zhao Zhiqin. Experimental study on the effect of PVA fiber length and content on the performance of engineering cement-based composites [J]. Railway Construction, 2014(03):115-117

Chheurn Chamnan, et. al. "Study on the Mechanical Properties of Ecological Engineeredcementitious Composite (ECO-ECC) Which Contained PVA Fiber and recycled Brick Powder Exposed To Low Temperature." *American Journal of Engineering Research (AJER)*, vol. 9(8), 2020, pp. 01-25.