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STRENGTHENING OF AMBIENT CURED QUARRY ROCK DUST INCORPORATED GEOPOLYMER CONCRETE BEAMS

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Abstract- Geopolymers concrete (GPC) has gained attraction in construction field due to low-carbon, cement less composite materials possessing considerably high mechanical properties and being used in numerous structural applications. On the other hand strengthening the structural members using advanced materials is a contemporary research in the field of repairs and rehabilitation. Carbon fiber reinforced polymer (CFRP) composite is becoming prominent in strengthening and rehabilitation to improve the flexure and shear strength of the structural members due to ease of installation, lower cost and time saving, strength and confinement gain and long-term durability. Most of the research works depicts the properties of GPC at elevated temperature which is costly and limit the field application but in this research work the beams were casted using quarry rock dust (QRD) which helps to improve the properties at ambient temperature. Very limited literature is available to improve the shear capacity of fiber reinforced GPC beams using CFRP. The purpose of this paper is to strengthen the pre-damaged shear deficient ambient cured GPC beams incorporated different combination of steel fibers (SF) and Sisal fibers (SsF) in mix design, with externally bonded CFRP composites. This paper also discuss the effect of natural fibers (i.e SsF, which has less environmental effect, used individually and in hybrid form) on fresh and mechanical properties of GPC and compare the ultimate load bearing capacity of strengthened and unstrengthen GPC beams. For this purpose a total of twenty four beams spanning 1000x150x150 mm were cast and tested under four point loading. Twelve of the beams were tested to failure while the remaining twelve were partially damaged by applying 60% of the ultimate load. The damaged beams were strengthened by applying CFRP strip at soffit of beams and U-shaped CFRP sheet near supports. The results showed that by applying CFRP strips and sheets, the ultimate load carrying capacity has increased significantly up to 45% relative to load capacity of the unstrengthen beam. The results demonstrated that the application of CFRP is an effective way to repair and strengthen the shear deficient/damaged GPC beams.

Keywords- Geopolymer beams, strengthening, sisal fibers, steel fibers, CFRP strips and sheets.

1 Introduction

The geopolymer concrete has gained attraction now days due to its remarkable capability of being able to replace cement concrete and possessing enhanced mechanical and serviceability criteria as compare to OPC based construction materials. In terms of global warming, the GPC could diminish the emission of CO2 to the atmosphere produced by the cement industries. Fly-ash (FA) and ground-granulated blast furnace slag (GBS) are the industrial waste/by products which are supplementary binding materials widely used for partial replacement of OPC due to their low cost and good binding or pozzolanic properties. The GPC incorporated with heat cured low calcium FA when tested in fresh and hard state has shown excellent mechanical properties and durability [1]. The quarry rock dust (QRD) is a residue and calcium rich material which can be used as a partial replacement of binder or filler material in GPC. This can help in reducing the environmental and land pollution by avoiding its deposition at landfills.

GPC has shown comparatively brittle behavior than OPC concrete [2]. But with the addition of fibers, GPC has improved behavior not only in splitting tensile strength, flexural strength and flexural toughness but also in the post-peak behavior i.e the stress-strain response in comparison from brittle to ductile [3]. There are many options of fibers for researchers such as steel fibers (SF), synthetic fibers and natural fibers. The SF are most widely used fibers since they show excellent properties both in OPC and GPC under fracture toughness, splitting tensile and flexural strengths [4] According to Food and Agriculture Organization of the United Nations (FAO) natural fibers are considered to be the future fibers due to the benefits to the environment [5]. The SsF plant absorb more CO2 than the oxygen they produce, and the organic wastes which are produced during preparation of SsF can be used in the feeding the animals, bioenergy generations and fertilizer production. [5]. It is therefore, a wise solution to add natural fibers as a reinforcing material to the composites based on geopolymer matrix.

During last three decades, different methods have been presented for strengthening and rehabilitation of structural elements but the application of CFRP is the most effective methods in the field of strengthening/rehabilitation due to its numerous advantages such as high strength-to-weight ratio, ease of installation, very high tensile strength and high modulus of elasticity, immunity from corrosion and durability of the CFRP composites [6]. CFRP significantly improve the shear and flexure capacity of damaged structural element which greatly extend their useful life [7].

The externally bonded CFRP strengthening method is an effect way to for strengthening the damaged beams to enhance their load bearing capacity [8]. Many researchers have recommended that the strengthening method with CFRP laminates can improve the behavior of the shear deficient beams effectively and increased their capacity upto 37% [7]. Using CFRP strips on bottom surface of elements and U-shaped on sides of element ascertained to be very effective way to increase the load carrying capacity and stiffness of strengthened element. Therefore, use of CFRP strengthening technique is gaining popularity in the construction filed and considered as a better choice for retrofitting/strengthening of structures [17]. Although there are many studies available to strengthening the beams but limited literature is available to the behavior associated with shear deficient GPC beams strengthened with CFRP.

The main objective of this paper is to study the behavior of fiber reinforced shear deficient and partially damaged GPC beams strengthened with CFRP laminates. The combination of binder materials and different percentage of fibers used in this study is quite new and there is no literature available on strengthening of beams casted using this combination at ambient cured condition. This paper also shed light on fresh and mechanical properties of GPC concrete using SF and SsF both individually and in hybrid form.

2 Experimental Program

In the first stage of experimental program, a mix design study was carried out for finding the optimum ratio of SsF and hybrid with SF for mixing in the GPC composites. The optimum value of SF was taken as 0.75% by weight of concrete from the previous study [9]. The mix ratios of the binders i.e. FA, GBS and QRD are taken as 50%, 35% and 15% respectively by weight from another study of the second author [9]. After identifying optimum ratios of fibers from the first stage, four mix types were considered as shown in Table 1. In the second stage of experimental program, 24 GPC beams were cast, six for each mix type. All beams have dimensions of 1000mm (L), 150mm (W), 150mm (H). In order to make shear deficient beams, 2 Nos 12mm bars are used as main bars and 2 Nos 9mm bars are used as anchor bars with shear reinforcement of 6mm dia bars @ 150 mm c/c.

All the beams were tested under four point loading following ASTM 78/C78M-21 [14] as shown in Figure 1. Out of the 24 beams, 12 beams were partially damaged by applying about 60% of the ultimate load while the remaining twelve beams were tested to failure. In the third and final stage of experimental program, the partially damaged beams were strengthened by CFRP strips and wraps as shown in Figure 2 to determine the enhancement in the load carrying capacity of the GPC beams.

Table 1. The types and mix proportions for casting the fiber-reinforced GPC beams

Concrete Quantities (Kg/m^3)

Samples	Mix ID	AL/B Ratio	W/C Ratio	Molarity of SH	SS/SH Ratio	B	Binder			CA 20mm	CA 10 mm	S	Alkaline Solution		SP	SF	SsF	W
							FA	GBS	QRD				SH	SS				
GPC beams without Fibers	GPC	0.5	0.5	12.0	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	3.8	-	-	9.1
GPC beams with 0.75% Steel Fibers	0.75SF-R-GPC	0.5	0.5	12.0	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	4.6	9.2	-	9.1
GPC beams with 0.5% Steel Fibres+1% Sisal Fibers	0.5SF+1Ss F-R-GPC	0.5	0.5	12.0	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	5.7	6.1	2.3	9.1
GPC beams with 2.4% Sisal Fibers	2.4SsF-R-GPC	0.5	0.5	12.0	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	7.8	-	5.5	9.1

Note: AL=Alkaline solution, B =Binder, W/C= water/cement ratio, SH= Sodium hydroxide, SS=Sodium silicate, FA= Flyash, GBS=Ground granulated blast furnace slag, QRD=Quarry rock dust , CA=Coarse aggregates, S= Sand, SP= Super plasticizer, SF= Steel fibers, SsF= Sisal fibers, W=Water

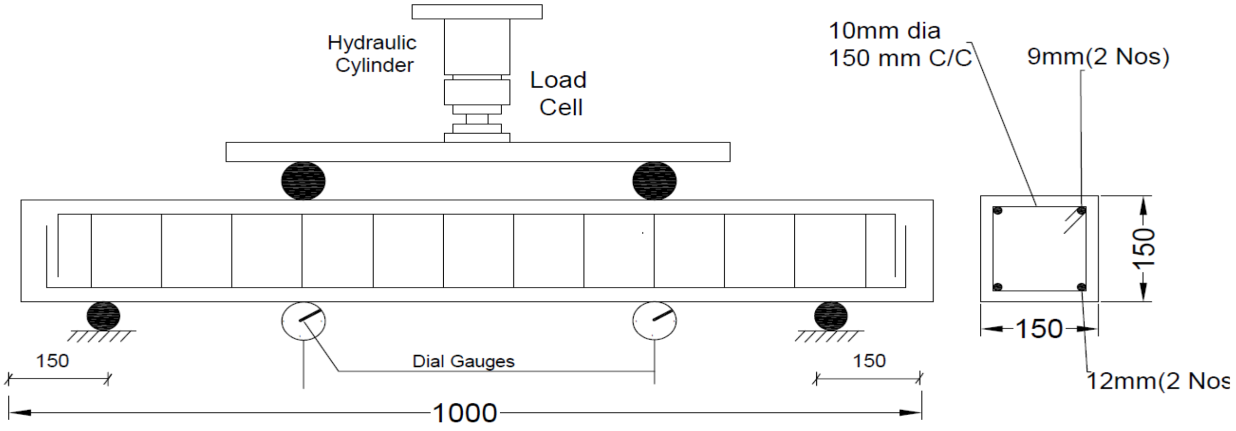

Figure 1: Test set up and reinforcement details (dimensions are in mm)

2.1 Materials used in the study

The commercially available FA of class-F is used for manufacturing of GPC. The QRD was collected from Margallah quarries in Taxila and grinded to cement size at Pakistan Council of Scientific and Industrial Research (PCSI) Peshawar, by ball Mill Machine. The GBS used as one of the binder material was obtained from Dewan steel mill Karachi. The alkaline liquid preparation materials used in this study were sodium silicate (SS) solution which is available in liquid form and sodium hydroxide (SH) which is in the form of pellets. The 12M SH solution was prepared by dissolving SH pallets with tap water, 24 hours before using it. The SS is added into solution of SH, 30 minutes prior to be added into the other materials. The coarse aggregate (CA) of varying size from 7mm to 20mm, from Margallah quarries was used. The aggregate crushing value and the aggregate impact value were found to be 22.7 and 19.48 respectively. The sand (S) used was clean dry Lawrancepur sand. The fineness modulus of sand was conformed to ASTM-C-136-06 [10] whereas specific gravity and water absorption was conforming to ASTM-C128-15 [11]. The Specific gravity of CA was conforming to ASTM-C127-07 [12]. The sisal fibers (SsF) were obtained from Ayub Research Centre (ARC) Faisalabad which has a water absorption capacity of 120% [13]. The SsF were cut into a size of 10 mm length with an average diameter of 137 µm resulting in an aspect ratio of 73. The both end hooked SF were used of a 35mm length, diameter of 0.50mm aspect ratio of 65 and tensile strength of 1350MPa.

A high strength, high elastic modulus, carbon fiber reinforced polymer (CFRP) wrap and strips by SIKA® were used for strengthening the damaged beams. The strips and wraps were bonded to concrete surface using epoxy adhesive. Table 2 presents the properties of the CFRP wrap and strips, as provided in the material's specifications of the manufacturer.

Table 2. The properties of CFRP laminates

Material	**Width (mm)**	**Thickness (mm)**	**Elastic Modulus (GPA)**	**Tensile Strength (MPA)**	**Elongation at break (%)**
CFRP strip (S812)	80	1.2	165	3100	1.69
CFRP wrap (230 C)	300	0.129	225	3500	1.59

2.2 Strengthening procedure.

To apply the CFRP strips and sheets, first the soffit and sides of damaged beams were grinded to make the surface levelled by removing the undulations and any adhered material. Next, the two parts of the epoxy adhesive Sikadur-30 were mixed to form epoxy paste. A layer of epoxy paste having thickness of 1.5mm was applied on concrete surface and CFRP strip. After the CFRP strip was placed on the concrete surface. The laminate is pressed until the adhesive is forced out on both sides as per recommended procedure. The CFRP strip is fixed throughout the length of beams and then confined with u shaped wrap near support using adhesive sikadur 330 in order to avoid the premature bond failure and strengthen the shear portion. Finally, grooved rollers were used on the attached CFRP sheets and left the beams undisturbed for 7 days. The beams were retested after strengthening till ultimate failure load as shown in Figure 2 (e) and (f).

a) Application of epoxy   b) Fixing of CFRP strip   c) Fixing of CFRP wrap

d) Completion of applying CFRP strip and wrap   e) The four point loading arrangement   f) The strengthen GPC beam at ultimate failure load

Figure2: The steps followed for strengthening the GPC beams and testing arrangement

3 Results and Discussion

3.1 Workability

The workability of mixes was checked using slump cone test. The slump value was maintained between 70 and 90 by varying the quantity of super plasticizer (SP) for a workable mixture. The slump vales for GPC, 2.4SsF-R-GPC, 0.5SF+1SsF-R-GPC and 0.75SF-R-GPC were calculated to be 84, 78, 75 and 78 mm respectively. The mixes with SsF has shown least slump value owing to their higher water absorption capacity and hollow cylindrical nature

3.2 Mechanical Properties

In order to obtain the optimum values of sisal fibers both individually and in hybrid form, the cube, cylinder and prism specimen were casted with mix proportion as mentioned in Table 3, and their mechanical properties were evaluated. The uniaxial compression strength test was conducted to determine cube strength after 28 days of casting following BS EN 12390-2:2009/EN 12390-3 and results are shown in Table 3. The maximum values were obtained in case of 0.5%SF+1%SisalF-R-GPC and 2.4%SisalF-R-GPC which are 44% and 39% more than the control mix respectively. The compressive strength has increase due to addition of fibers both individually as well as in hybrid but with the increase of fibers content in hybrid form (0.5SF+1.5SsF-R-GPC), there is decrease in the compressive strength due to low workability because of higher fiber content.

The split cylinder strength is checked with cylinders after 28 days of casting following ASTM C496/496M and the results are shown in Table 3. The maximum results were achieved in case of 0.5%SF+1%SisalF-R-GPC and 2.4%SisalF-R-GPC which are 43% and 32% more as compare to the control mix respectively. The failure of fiber reinforced GPC was accompanied by the multi cracking due to fact that fibers allow load transference from the cracked area to the other parts of the specimen. These results are in same pattern with what observed by the other researchers [15] as far mode of failure is concerned.

Like the compressive and tensile strength the flexural strength has also shown similar trend with the increase of fiber content with maximum values at 0.5%SF+1%SisalF-R-GPC and 2.4%SisalF-R-GPC which are 65% and 55% more relative to the control mix respectively. It is observed that the increase in strength is more dominant in case of flexural behavior due to the fact that fibers help to bear more load across the cracks, resist the penetration of the cracks and fibers stretching and elongation is observed especially in case of flexural testing of specimens as also observed by Sun et al. [15] and Chen et al. [16].

Table 3. The mechanical properties of mix design with different combination of fibers

Material	**Compressive Strength (MPA)**	**Split Cylinder Strength (MPA)**	**Flexure Strength (MPA)**	**Increase in Compressive Strength**	**Increase in Split Cylinder Strength**	**Increase in Flexure Strength**
GPC (Control mix)	20.5	1.89	2.23	-	-	-
0.5%SF+0.5%SisalF-R-GPC	24.2	2.5	3.12	18%	32%	40%
0.5%SF+1%SisalF-R-GPC	29.5	2.75	3.67	44%	46%	65%
0.5SF%+1.5%SisalF-R-GPC	24.8	2.7	3.21	21%	43%	44%
0.8%SisalF-R-GPC	23.24	2	2.45	13%	6%	10%
1.2%SisalF-R-GPC	26.340	2.300	2.89	28%	22%	30%
2.4%SisalF-R-GPC	28.560	2.500	3.45	39%	32%	55%

4 *Load Carrying Capacity of Strengthened GPC Beams*

A total of twenty four beams were tested under four point loading as shown in Figures 1 and Figure 2. Out of 24 beams, 12 beams were partially damaged and remaining 12 beams were tested to failure. The substantially damaged beams were strengthened and re-tested till failure to find out the ultimate load bearing capacity. The results showed that the ultimate load carrying capacity of strengthened beams is higher relative to the control unstrengthen beams in all cases. The average increase in ultimate strength of retrofitted GPC beams viz. GPC, 0.75SF-R-GPC, 0.5SF-1SsF-R-GPC, and 2.4SsF-R-GPC was 20%, 24%, 43% and 45% respectively as compared to non-strengthened beams. The comparison of ultimate load carrying capacity of original beams and retrofitted beams is shown in Figure 3. All the strengthened beams failed due to formation shear cracks and same behavior is observed in unstrengthen beams. However the significant increase in load bearing capacity and high ductile behavior of the strengthened beams observed due to usage of CFRP composites. The ductile behavior is obtained due to high tensile strength of CFRP which can provide ample warning before the ultimate failure. The use of CFRP helped to delay the initial cracks and their further propagation in the beam resulting the increase in load bearing capacity.

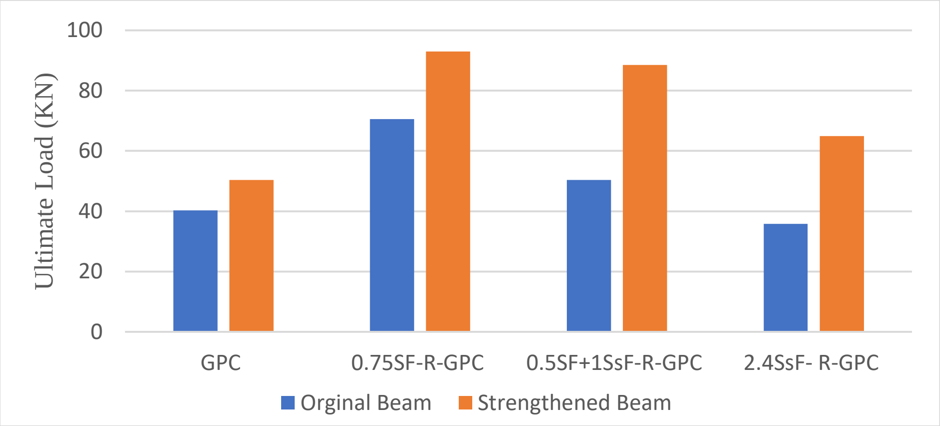

Figure 3: The comparison of ultimate load capacity of original and strengthened beams

5 *Load Deflection Curve*

Two dial gauges were used under the test specimens in order to observe the deflection values. The curve was plotted using mid deflection values with respect to load which is termed as load deflection curve. The strengthened beams have steeper load-deflection curve and higher load bearing capacity due to enhanced stiffness provided the CFRP strengthening system as shown in Figure 4. The same behavior was observed by Lavorato, D.,A [7]. The stiffness has increased due to high tensile strength of CFRP laminates which delays and prevent the cracks propagation by transferring the load from beam to CFRP strengthening system.

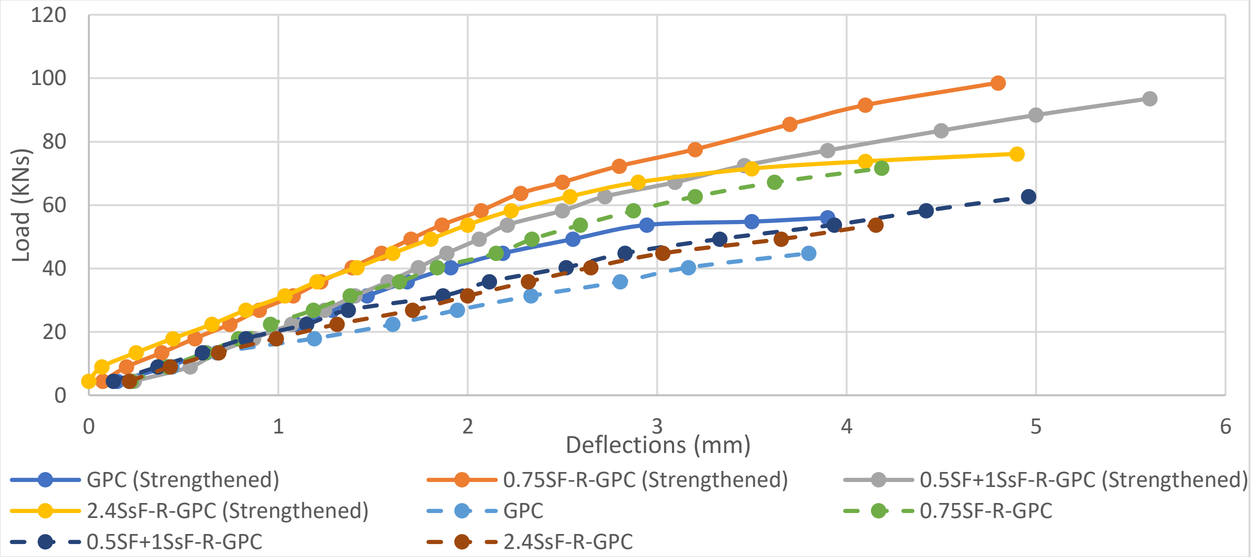

Figure 4: The load deflection curve of strengthened unstrengthen GPC beam

6 Practical Application

The use of GPC concrete is gaining popularity in construction field and but there are limited studies available to strengthen the shear deficient fiber reinforced GPC beams cured at ambient temperature. The CFRP strengthening regime of shear deficient GPC beams will not only improve/restore the load bearing capacity but also save the time and cost required to dismantle and reconstruct the structural element. This will help to repair and improve the capacity of structural elements and increase the serviceability of the structures.

7 Conclusion

Following conclusions can be drawn from the conducted study:

- Sisal fibers have good having good mechanical properties and lesser environmental impact. The addition of Ssf both individually and in hybrid form with SF into QRD incorporated GPC at various fraction has yielded improved performance in mechanical properties and flexural strength relative to control specimen.
- The addition of fibers both individually and in hybrid form has increased the load bearing capacity of all GPC beams and the maximum value is obtained at 0.75% steel fiber which is 75% higher than the counterpart GPC.
- The pre-damaged GPC beams strengthened with CFRP strips and CFRP wraps has increased the ultimate load capacity relative to control unstrengthen beams.
- The ultimate load carrying capacity has increased significantly up to 45% relative to load capacity of the unstrengthen beam due to high tensile strength of CFRP laminates.
- The strengthened beam with 0.75% SF has shown maximum load capacity. The other strengthened beams has also shown improved results and significantly enhanced the load bearing capacity relative to the control beams
- The mode of failure in all beams is due to formation of cracks near supports which travelled towards point of impact. However in case of strengthened beams the CFRP delays the initial cracks and further propagation which results in increased load bearing capacity of beams.
- The strengthened beams have steeper load deflection curve due to high tensile strength of CFRP laminates which can give us enough warning before ultimate failure.

References

[1] Nath, P. and P. K. Sarker (2014). "Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition." Construction and Building Materials 66: 163-171.
[2] Thomas RJ, Peethamparan S Engg properties and stress–strain behavior. Constr Build Mater 2015;93:49–56.
[3] Khan MZN, Hao Y, Hao H, Shaikh FUA. Mechanical properties of ambient cured high strength hybrid steel and synthetic fibers reinforced geopolymer composites.Cem Concr Compos 2018;85:133–52.
[4] Ali Nazari, "Flexural strength of plain and fibre-reinforced boroaluminosilicate geopolymer", Const and Build Mat 76 (2015) 207–213
[5] Guido Silva, Suyeon Kim (2020). Optimization of a reinforced geopolymer composite using natural fibers and construction wastes. Construction and Building Materials 258 (2020) 119697.
[6] Danraka, M. N., H. M. Mahmod, O.-k. J. Oluwatosin and P. Student (2017). "Strengthening of Reinforced Concrete Beams using FRP Technique: A Review." International Journal of Engineering Science 7(6):13199.
[7] Lavorato, D., A. V. Bergami, G. Fiorentino, A. Fiore, S. Santini and C. Nuti (2018). "Experimental tests on existing RC beams strengthened in flexure and retrofitted for shear by C-FRP in presence of negative moments." International Journal of Advanced Structural Engineering: 1-22.
[8] Osman, B. H., et al. (2019). Effect of reinforcement ratios on shear behavior of concrete beams strengthened with CFRP sheets. HBRC Journal,14(1), 29–36.
[9] Muhammad Ibraheem, Faheem Butt. Fresh and Mechanical Properties of Ambient Cured Ternary Blended Geopolymer Concrete Reinforced With Steel Fibers. 2nd Conference on Sustainability in Civil Engineering (CSCE'20), CUST Islamabad.
[10] ASTM C136-06, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," ASTM Int., 2006.
[11] ASTM C128-15, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate," ASTM Int., 2015.

[12] ASTM C127-07, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate," ASTM Int., 2007

[13] Tung T. Tran "Experimental and analytical investigation on flexural behaviour of ambient cured geopolymer concrete beams reinforced with steel fibers", Engineering Structures 200 (2019) 109707

[14] Abdul Saboor Karzad, Moussa Leblouba," Repair and strengthening of shear-deficient reinforced concrete beams using Carbon Fiber Reinforced Polymer", Composite Structures 223 (2019) 110963

[15] P. Sun, H. Wu, Transition from brittle to ductile behavior of fly ash using PVA fibers, Cem. Concr. Compos. 30 (1) (2008) 29–36

[16] R. Chen, S. Ahmari, L. Zhang, Utilization of sweet sorghum fiber to reinforce fly ash-based geopolymer, J. Mater. Sci. 46 (6) (2014) 2548–2558

[17] Salama, A. S. D., Hawileh, R. A., & Abdalla, J. A. (2019). Performance of externally strengthened RC beams with side-bonded CFRP sheets. Composite Structures,212, 281–290.