Jurnal Kejuruteraan 34(2) 2022: 309-315
https://doi.org/10.17576/jkukm-2022-34(2)-14

Preliminary Investigation on Properties of Novel Sustainable Composite: Fish Scales Reinforced Cement Concrete

Fahad Ahmed Arain, Masroor Ali Jatoi, Muhammad Saleem Raza*, Fahad Ali Shaikh, Farhan Khowaja & Kunal Rai

[a]*Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro-76062, Sindh, Pakistan.*

Corresponding author: saleemraza43@yahoo.com

Received 30 June 2021, Received in revised form 18 August 2021
Accepted 19 September 2021, Available online 30 March 2022

ABSTRACT

This study focused on analysing the effect of fish scales reinforcement on fresh and hardened-state properties of concrete. For this purpose, 24 cubes and 24 cylinders were casted at a design mix ratio of 1:2.3:4.3. The water-cement ratio of 0.57 was maintained. The fish scales reinforcement levels of 0%, 1%, 1.5% and 2% by weight of cement were maintained for casting of specimens. For fresh-state assessment, the workability of concrete mixes was observed by slump test and the results showed that, with the addition of fish scales, the slump value decreased due to increase in water demand. With the addition of 2% Fish Scales, the workability of concrete mixes reduced by 36.40%. The compressive strength and tensile strength of concrete cubes and cylinders were tested with Universal Testing Machine (UTM) at curing period of 7 and 28 days. Out of 48 specimens casted, a total of 24 specimens were subjected to compressive strength test while other 24 specimens were tested for tensile strength. The results reported that with addition of 2% fish scales in concrete, the tensile strength of concrete increased but the compressive strength initially decreased and later increased. It can thus be concluded that the fish scales can be incorporated in concrete with steel to enhance the tensile strength of concrete. Keeping the initial decrease in compressive strength of concrete in consideration, it can be recommended that the fish scale reinforced concrete can be safely used in light weight structures and non-structural elements like floor slabs and ribs.

Keywords: Concrete; fish scales; compressive strength; tensile strength; workability

INTRODUCTION

Concrete is a widely used material in global construction sector. It is basically a blend of aggregates, water, and binder i.e. lime, cement etc. (Ali et al. 2020). The properties of concrete such as economic feasibility, unavoidable dependency and versatile nature have made this material most widely used among the construction industry practitioners (Bheel et al. 2018; Jatoi et al. 2019; Mangi et al. 2020; Nguyen et al. 2018). With the increase in population and urbanization, there is a need of infrastructure development which requires the services of construction sector. The conventional methods and materials of this industry have been deemed to be responsible for emission of greenhouse gases in atmosphere resulting a polluted environment (Bheel et al. 2018; Chowdhury et al. 2015). Therefore, researchers, across the globe, are striving to reduce the usage of raw materials incorporated in formation of concrete, and the key element out of all such materials is cement. The manufacturing of cement is globally considered responsible for 5-10% of CO_2 emissions which is causing detrimental effects to our living environment (Jhatial et al. 2019; Krishna et al. 2016). Hence, it is a need of hour that the demand and production of cement should be reduced so that the energy consumption can, consequently, be reduced to avoid the contamination of environment (Hussein et al. 2014; Memon et al. 2021). One of the techniques considered for reduction of usage and production of raw materials of concrete is to make use of the waste materials carrying pozzolanic and cementitious characteristics (Idris & Yassin 2015). Numerous wastes such as Coal Ash, Fly Ash, Ground Granulated Blast Furnace Slag, Steel Slag, Rice Husk Ash, Waste Lime Sludge, Palm Oil Fuel Ash, Biomass Combustion Ash, Sewage Sludge Ash etc. have been used by researchers in production of concrete for reduced the usage of binder, efficient waste management, encouragement of green environment and improved properties of concrete (Adesina & Olutoge 2019; Hamada et al. 2019; Lynn et al. 2015; Mangi et al. 2019; Nagrockienė & Daugėla 2018; Roy & Krishna 2015; Sangeetha 2018; Zhang et al. 2019). Moreover, the enhancement of strength of concrete with incorporation of supplementary cementitious materials and fibers has been in practice since long (Raza et al. 2020).

The waste material employed in this research is fish scales of carp i.e. fresh-water fish. Scales are the protective covering on the body of fish and many other vertebrates. Fish scale is one of the natural debris which is produced by fish industry all over the world (Torres et al. 2008). The size, quantity and even shape of scales on every species of fish might be unique and vary according to the specie and age of

fish. For example: scales of carp (a specie of fresh-water fish whose scales are used in this study) are leaf like in shape and may vary according to its age. On the other hand, trout have small bead shaped scales and shark have very small sharp and rough sandpaper like scales and are very difficult to see with naked eye (Gopi et al. 2016). In order to ensure the synchronization of process and similarity of results, scales of only one species carp has been incorporated in concrete mixes.

The functionality and performance of fish scales in structural concrete is very unpredictable and uncertain till now, as no well-known research is done on this topic of adding fish scales to the concrete. Moreover, it is an established fact that concrete is weak in tensile zone and hence, its reinforcement with fibers is considered as a conventional, viable and practical solution. The review of literature suggests that the inclusion of fibers dates to 1900s but no work, considering the use of fish scales as fibrous additives in concrete, was reported. The present research has intended to fill this gap. The reason behind choosing fish scales for this study is the set of expected advantages, such as it is an organic and non-reactive material by nature, hence it will not react with constituents of cementitious material or admixtures in any negative manner. Secondly, it can be considered as a green and environment friendly material because it is readily available and is used without further processing so it will not increase the carbon footprint. Moreover, it is very cheap material (Reza Atefi et al. 2012). Last but not the least, fish scales are good in tensile strength as (Torres et al. 2008) and (Ikoma et al. 2003) reported for high tensile strength and Young's modulus of Arapaima Gigas Fish Scales and Teleost species of Fish Scales respectively.

The aim of present research is to study the potential of fish scales as reinforcement with cement, as an additive material to investigate the properties of the concrete. The specific objectives were set based on aim of this research include quantification of the influence of fish scales reinforcement on workability, compressive strength, and tensile strength of cement concrete and to compare the results with the behavior of plain cement concrete.

MATERIALS AND MIX DESIGN

For this experimental study, cement produced in Lucky Cement Factory located at Nooriabad, Pakistan was used which conformed to standards set in (*ASTM C150 / C150M-19a, Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA*, 2019). The important tests on cement such as fineness test, consistency test and initial and final setting time tests were performed in Concrete Laboratory of Department of Civil Engineering, Mehran UET Jamshoro. The fineness of cement was found to be 93%. The initial and final setting time of cement was found to be 115 minutes and 228 minutes respectively. Pure and neutral drinking water was used in this research at various stages of mixing and curing. The fish scales included in concrete for this research work were obtained from local fish vendors in Hyderabad. For the sake of similarity of results, scales of single species of fish called carp were used. Carp is a similar specie to the goldfish but larger in size and easily available everywhere in Hyderabad. The range of size of fish scales set after washing and drying was 3-15 mm. The fine and coarse aggregates available in Jamshoro were used in this research. The fine aggregates were subjected to sieve analysis, water absorption and specific gravity tests as specified in (*ASTM C128 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*, 2015). The specific gravity of fine aggregates came out to be 2.68 while the water absorption of fine aggregates was calculated to be 2.07%. Similarly, for coarse aggregates, fundamental characteristics such as water absorption and specific gravity were found to be 1.6% and 2.7 respectively. The weight of sample in both cases was set to be 5kg.

Mix design is the process of selecting suitable ingredients of concrete viz. cement, fine and coarse aggregates etc. and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. In this research, with the ratio of 1:2.3:4.3 was adopted. Total 48 number of specimens (24 cylinders and 24 cubes) were prepared for analysis. For every inclusion level of fish scale/ in concrete such as 0%, 1%, 1.5% and 2%, six cylinders (4 inches diameter and 8 inches height) and six cubes (4"x4"4") were casted. The quantities of concrete ingredients for casting of cylinders and cubes, and mix ratio were calculated by means of DoE method and are tabulated in Table 1.

RESEARCH METHODOLOGY

To conduct this research, a total of 48 specimen (24 cylinders and 24 cubes) were casted as detailed in Table 2. Out of 48 total specimens, twenty-four were subjected to compressive strength test and twenty-four were subjected to tensile strength test, both at 28 days of curing. Fish scales were included in concrete at different percentages i.e. 1%, 1.5% and 2% by weight of cement.

TABLE 1. Quantities of Materials required for Preparation of Concrete Specimens

S. No.	Mix ID	Mix Ratio	Cement (%)	Fine Aggregates (%)	Coarse Aggregates (%)	W/C Ratio
1.	FSRC0	1: 2.3: 4.3	100	100	100	0.57
2.	FSRC1	1: 2.3: 4.3	100	100	100	0.57
3.	FSRC1.5	1: 2.3: 4.3	100	100	100	0.57
4.	FSRC2	1: 2.3: 4.3	100	100	100	0.57

For both cubes and cylinders, six each number of specimens were casted at 0%, 1%, 1.5% and 2% inclusion level of fish scales. The workability of concrete mixes was determined through slump cone method in accordance with ASTM C143 (*ASTM C143 / C143M - 15a Standard Test Method for Slump of Hydraulic-Cement Concrete*, n.d.) while the compressive and tensile strength of concrete was determined through Universal Testing Machine (UTM) by following ASTM C39 (*ASTM C39 / C39M - 20 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, 2020) and ASTM C496 (*ASTM C496 / C496M - 17 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, n.d.) standards, respectively.

TABLE 2. Details of Concrete Specimens Casted

Mix Design Details		Compressive Strength Cubes		Tensile Strength Cylinders	
Mix ID	Fish Scales	7 Days	28 Days	7 Days	28 Days
FSRC0	0%	3	3	3	3
FSRC1	1%	3	3	3	3
FSRC1.5	1.5%	3	3	3	3
FSRC2	2%	3	3	3	3
Total Specimens		12 + 12= 24 Cubes		12 + 12= 24 Cylinders	

RESULTS AND DISCUSSIONS

WORKABILITY OF FISH SCALES REINFORCED CONCRETE

The workability of concrete reinforced with fish scales as an additive was assessed through slump cone test under the guidelines prescribed in ASTM C143 standard (*ASTM C143 / C143M - 15a Standard Test Method for Slump of Hydraulic-Cement Concrete*, n.d.). The slump cone method is a quick and economical test and, is carried out from batch to batch to check the uniform quality of concrete during construction. The relation between percentage of fish scales incorporated in concrete and its workability is depicted in Figure 1. The results indicate that the slump value of concrete mix decreases with addition of fish scales in different percentages i.e. 1%, 1.5% and 2%. In other words, the workability or consistency of concrete keeps on decreasing with inclusion of fish scales in it due to increase in water demand. The results align with the findings of study conducted by (Varma & Kumar, 2019), on workability of concrete blended with fish scales for rigid pavements. Nevertheless, it is a well-established fact from available literature, that additives and/or fibers increase the water demand of concrete by absorbing more amount of water, resulting in lesser workable and flowable concrete (Afroughsabet et al. 2016; Bheel et al. 2020; Jhatial et al. 2018; Meghwar et al. 2020; Okeola et al. 2018; Raval & Patel, 2015; Salih et al. 2019; Shaikh et al. 2020).

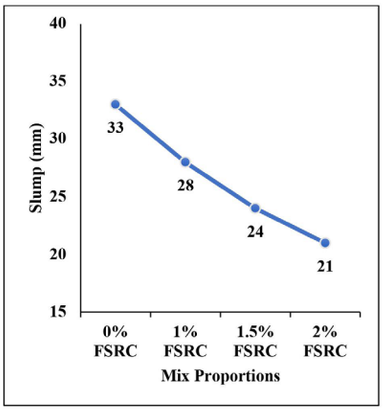

FIGURE 1. Workability of fish scales reinforced concrete

COMPRESSIVE STRENGTH OF FISH SCALES REINFORCED CONCRETE

The compressive strength of concrete is the capacity of concrete to withstand loads tending to break the specimen. This is the utmost important test which depicts characteristics of concrete (Raza et al. 2020) and hence, is deemed to have key value for design of structures. The compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material and quality control during production of concrete etc. The

test for compressive strength is carried out on cubes in Universal Testing Machine as per guidelines specified in ASTM C39 (*ASTM C39 / C39M - 20 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, 2020). The test results based on concrete cubes of different percentage of Fish scales used at 7 and 28 days of curing depict that addition of fish scales in concrete mixes reduce the compressive strength of concrete as depicted in Figure 2. However, with the increase in fish scales content, the strength started developing at later reinforcement levels which implies that enough potential of fish scales for strengthening of concrete. Such phenomenon can be credited to the fact that introduction of fibrous additives in concrete tends the aggregates to enter the pores to ensure adequate bonding but rise in fiber content results in bulkiness which distorts the adhesion to yield lesser strength. Moreover, the formation of weaker transition zone around the fibers tend to make the entire concrete specimen weaker. In addition, the impurities present on fiber surface and the thickness of fibers can also hinder the improvement in bonding of concrete ingredients. Hence, it can be concluded that, although fibers increase the strength of concrete, but there always occurs an optimum fiber inclusion level (Ranjitham et al. 2019). In this case, the optimum inclusion level is 2%, however, research at increased level of reinforcement will demonstrate the overall influence on strength of concrete.

TENSILE STRENGTH OF FISH SCALES REINFORCED CONCRETE

The results of tensile strength test (ASTM C496/C496M–17) were based on testing of cylinders with different percentages of fish scales for 7 and 28 days of curing. During the tensile strength test, concrete specimens were tested by applying increasing load along the vertical diameter until failure (split) occurs. Failure of the specimen occurs along its vertical diameter, due to tension developed in the transverse direction. It is clear from results that the tensile strength of concrete cylinders increased by adding fish scales. The maximum value of tensile strength is obtained at 2% addition level of fish scales in concrete mixes i.e. 4.03 MPa. This behavior of concrete is due to high tensile strength of fish scales. Moreover, (Bheel et al. 2020) also suggested that inclusion of fibrous additives in concrete body supplement the tensile strength of concrete. The tensile strength test results of fish scales reinforced concrete are shown in Figure 3.

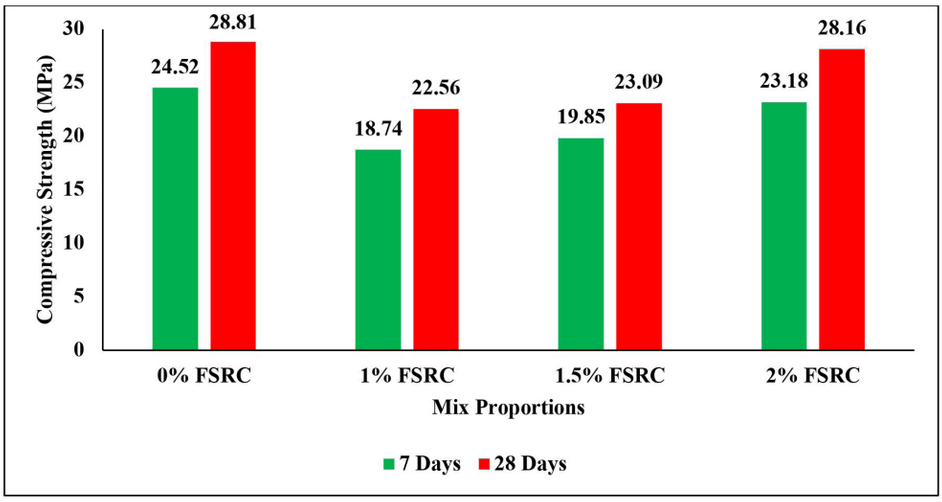

FIGURE 2. Compressive Strength of Fish Scales Reinforced Concrete

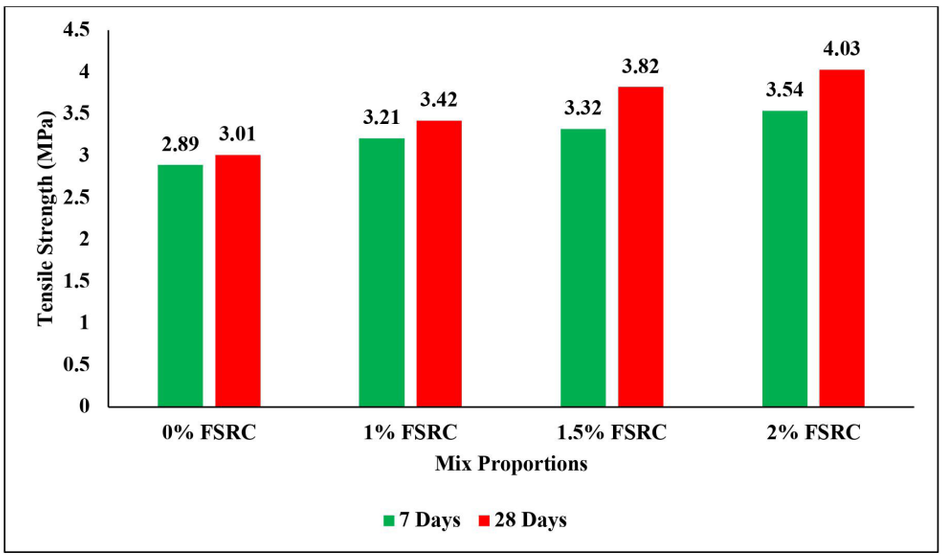

FIGURE 3. Tensile strength of fish scales reinforced concrete

CONCLUSIONS AND FUTURE RECOMMENDATIONS

The test results indicate that as the amount of fish scales as an additive reinforcement increases, the workability of concrete mix decreases due to occurrence of higher water demand by concrete mix.

The increased percentage i.e. 1.5% and 2% of fish scales will give high tensile strength of concrete. On contrary, the inclusion of fish scales shows divert effects on compressive strength of concrete. The results depict that compressive strength of concrete cubes shows variation as it decreases by adding 1% fish scale and again increase at 1.5% and 2% fish scales respectively. Fish scales in concrete grip the concrete particles when load is applied on it until it reaches its failure. It is noticed that there is no chemical or physical reaction of concrete with fish scales. In other words, fish scales remain as inert material which helps in gaining increase in tensile strength of concrete.

Considering the compressive strength of fish scales reinforced concrete, it can be recommended to be used for light weight structures. As the fish scales help in increasing tensile strength of concrete, the fish scales can be used with main steel in reinforced concrete to increase the tensile and flexural strength. The fish scales can be used for nonstructural cement concrete in buildings such as floor slabs, floor ribs, underground slabs, behind building stones and in partitions etc. It is recommended to study the effect of large size of fish scales (other than carp fish) on fresh and hardened properties of concrete. Moreover, the effects on properties of concrete should also be studied after 56 and 90 days of curing of concrete specimen. The chemical, mechanical and fire resistance behavior of fish scale reinforced concrete should also be studied.

ACKNOWLEDGMENT

The authors are highly indebted to Mehran University of Engineering and Technology, Jamshoro Campus, Sindh, Pakistan for provision of facilities required in the conduct of this experimental work.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Adesina, P. A., & Olutoge, F. A. 2019. Structural properties of sustainable concrete developed using rice husk ash and hydrated lime. *Journal of Building Engineering* 25(April): 100804. https://doi.org/10.1016/j.jobe.2019.100804

Afroughsabet, V., Biolzi, L., & Ozbakkaloglu, T. 2016. High-performance fiber-reinforced concrete: a review. In *Journal of Materials Science* (Vol. 51). Springer US. https://doi.org/10.1007/s10853-016-9917-4

Ali, S., Kumar, H., Rizvi, S. H., Raza, M. S., & Ansari, J. K. 2020. Effects of Steel Fibers on Fresh and Hardened Properties of Cement Concrete. *Civil and Environmental Engineering Reports* 30(3): 186–199. https://doi.org/10.2478/ceer-2020-0039

ASTM C128 - 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. (2015). https://doi.org/10.1520/C0128-15

ASTM C143 / C143M - 15a Standard Test Method for Slump of Hydraulic-Cement Concrete. (n.d.). Retrieved March 24, 2020, from https://www.astm.org/Standards/C143

ASTM C150 / C150M-19a, Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA (pp. 1–10). (2019). https://doi.org/10.1520/C0150_C0150M-19A

ASTM C39 / C39M - 20 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. 2020. https://doi.org/10.1520/C0039_C0039M-20

ASTM C496 / C496M - 17 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. (n.d.). Retrieved March 24, 2020, from https://www.astm.org/Standards/C496

Bheel, N., Awoyera, P., Aluko, O., Mahro, S., Viloria, A., & Sierra, C. A. S. 2020. Sustainable composite development: Novel use of human hair as fiber in concrete. *Case Studies in Construction Materials* 13. https://doi.org/10.1016/j.cscm.2020.e00412

Bheel, N., Meghwar, S. L., Abbasi, S. A., Marwari, L. C., Mugeri, J. A., & Abbasi, R. A. 2018. Effect of Rice Husk Ash and Water-Cement Ratio on Strength of Concrete. *Civil Engineering Journal* 4(10): 2373–2382. https://doi.org/10.28991/cej-03091166

Chowdhury, S., Mishra, M., & Suganya, O. 2015. The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview. *Ain Shams Engineering Journal* 6(2): 429–437. https://doi.org/10.1016/j.asej.2014.11.005

Gopi, V., Arun, S. C., Gopi, A., Sankaranarayanan, S., & Raj, S. S. 2016. Characterization of fish scale reinforced composites. *International Journal of Engineering Science and Computing* 6(5): 5227–5230. https://doi.org/10.4010/2016.1282

Hamada, H. M., Yahaya, F. M., Muthusamy, K., Jokhio, G. A., & Humada, A. M. 2019. Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash. *Construction and Building Materials* 214: 344–354. https://doi.org/10.1016/j.conbuildmat.2019.04.101

Hussein, A. A. E., Shafiq, N., Nuruddin, M. F., & Memon, F. A. 2014. Compressive strength and microstructure of sugar cane bagasse ash concrete. *Research Journal of Applied Sciences, Engineering and Technology 7*(12): 2569–2577. https://doi.org/10.19026/rjaset.7.569

Idris, M. K., & Yassin, K. E. E. 2015. Determination of the effects of bagasse ash on the properties of portland cement. *Journal of Applied and Industrial Sciences* 3(1): 6–11.

Ikoma, T., Kobayashi, H., Tanaka, J., Walsh, D., & Mann, S. 2003. Physical properties of type I collagen extracted from fish scales of Pagrus major and Oreochromis niloticas. *International Journal of Biological Macromolecules* 32: 199–204. https://doi.org/10.1016/S0141-8130(03)00054-0

Jatoi, M. A., Solangi, G. S., Shaikh, F. A., Khan, S., & Ahmed, S. 2019. Effect of lakhra fly ash as partial replacement of cement in traditional concrete. *Mehran University Research Journal of Engineering and Technology* 38(4): 1045–1056. https://doi.org/10.22581/muet1982.1904.16

Jhatial, A. A., Sohu, S., Bhatti, N., Lakhiar, M. T., & Oad, R. 2018. Effect of steel fibres on the compressive and flexural strength of concrete. *International Journal of Advanced and Applied Sciences* 5(10): 16–21. https://doi.org/10.21833/ijaas.2018.10.003

Jhatial, A. A., Sohu, S., Memon, M. J., Bhatti, N. ul K., & Memon, D. 2019. Eggshell powder as partial cement replacement and its effect on the workability and compressive strength of concrete. *International Journal of Advanced and Applied Sciences* 6(9): 71–75. https://doi.org/10.21833/ijaas.2019.09.011

Krishna, N. K., Sandeep, S., & Mini, K. M. 2016. Study on concrete with partial replacement of cement by rice husk ash. *IOP Conference Series: Materials Science and Engineering*, 149(012109): 1–12. https://doi.org/10.1088/1757-899X/149/1/012109

Lynn, C. J., Dhir, R. K., Ghataora, G. S., & West, R. P. 2015. Sewage sludge ash characteristics and potential for use in concrete. *Construction and Building Materials* 98: 767–779. https://doi.org/10.1016/j.conbuildmat.2015.08.122

Mangi, S. A., Ibrahim, M. H. W., Jamaluddin, N., Arshad, M. F., & Mudjanarko, S. W. 2019. Recycling of coal ash in concrete as a partial cementitious resource. *Resources* 8(99): 1–10. https://doi.org/10.3390/resources8020099

Mangi, S. A., Makhija, A., Raza, M. S., Khahro, S. H., & Jhatial, A. A. 2020. A comprehensive review on effects of seawater on engineering properties of concrete. *Silicon*. https://doi.org/10.1007/s12633-020-00724-7

Meghwar, S. L., Khaskheli, G. B., & Kumar, A. 2020. Human scalp hair as fiber reinforcement in cement concrete. *Mehran University Research Journal of Engineering and Technology* 39(2): 443–452. https://doi.org/10.22581/muet1982.2002.20

Memon, M. J., Jhatial, A. A., Murtaza, A., Raza, M. S., & Phulpoto, K. B. 2021. Production of eco-friendly concrete incorporating rice husk ash and polypropylene fibres. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-13418-3

Nagrockienė, D., & Daugėla, A. 2018. Investigation into the properties of concrete modified with biomass combustion fly ash. *Construction and Building Materials* 174: 369–375. https://doi.org/10.1016/j.conbuildmat.2018.04.125

Nguyen, H., Carvelli, V., Adesanya, E., Kinnunen, P., & Illikainen, M. 2018. High performance cementitious composite from alkali-activated ladle slag reinforced with polypropylene fibers. *Cement and Concrete Composites* 90: 150–160. https://doi.org/10.1016/j.cemconcomp.2018.03.024

Okeola, A. A., Abuodha, S. O., & Mwero, J. 2018. Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. *Fibers* 6(3): 1–16. https://doi.org/10.3390/fib6030053

Ranjitham, M., Mohanraj, S., Ajithpandi, K., Akileswaran, S., & Sree, S. K. D. 2019. Strength properties of coconut fibre reinforced concrete. *AIP Conference Proceedings* 2128: 1–8. https://doi.org/10.1063/1.5117917

Raval, G., & Patel, U. 2015. Impacts of adding Jute fibers to concrete. *International Journal of Advance Engineering and Research Development* 5(3): 1–8.

Raza, M. S., Rai, K., Kumar, D., & Ali, M. 2020. Experimental study of physical, fresh-state and strength parameters of concrete incorporating wood waste ash as a cementitious material. *Journal of Materials and Engineering Structures* 7(2): 267–276.

Reza Atefi, Razmavar, A., Teimoori, F., & Teimoori, F. 2012. Mechanical characterization, fabrication and FTIR spectroscopic analysis of fish scale reinforced epoxy composites. *Life Science Journal* 9(2): 1080–1082.

Roy, D. K. S., & Krishna, P. C. S. 2015. Performance of high volume fly ash concrete using local power plant fly ash. *International Journal of Composite and Constituent Materials* 1(1): 7–13.

Salih, Y. A., Sabeeh, N. N., Yass, M. F., Ahmed, A. S., & Khudhurr, E. S. 2019. Concrete beams strengthened with jute fibers. *Civil Engineering Journal* 5(4): 767–776. https://doi.org/10.28991/cej-2019-03091286

Sangeetha, S. P. 2018. Strength and flexural behaviour of reinforced concrete with ground granulated blast furnace slag. *International Journal of Pure and Applied Mathematics* 118(5): 867–879.

Shaikh, A. R., Memon, M. J., Keerio, M. A., & Khaskheli, Z. H. 2020. Effect of amount and length of nylon fibres on the properties of concrete. *International Journal of Modern Research in Engineering and Management* 3(1): 6–13.

Torres, F. G., Troncoso, O. P., Nakamatsu, J., Grande, C. J., & Gómez, C. M. 2008. Characterization of the nanocomposite laminate structure occurring in fish scales from Arapaima Gigas. *Materials Science and Engineering C*. 28(8): 1276–1283. https://doi.org/10.1016/j.msec.2007.12.001

Varma, D. S. A., & Kumar, S. N. 2019. Effect of fish scales on workability of concrete for rigid pavements. *International Journal for Scientific Research & Development* 7(6): 463–467.

Zhang, X., Zhao, S., Liu, Z., & Wang, F. 2019. Utilization of steel slag in ultra-high performance concrete with enhanced eco-friendliness. *Construction and Building Materials* 214: 28–36. https://doi.org/10.1016/j.conbuildmat.2019.04.106