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Research Article

Prediction of tensile strength of concrete produced by using pozzolanic materials and partly replacing natural sand by manufactured sand

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ABSTRACT

The overuse level of cement and natural sand for civil industry has several undesirable social and ecological consequences. As an answer for this, industrial wastes or by-products (pozzolanic materials) such as fly ash, GGBFS, silica fume and metakaolin can be used to interchange partially cement and natural sand by manufacturing sand (M-sand). In this study, Artificial Neural Networks (ANNs) models were developed for predicting the tensile strength, at the age of 28 days, of concretes containing partly pozzolanic materials and partly replacing natural sand by manufactured sand. Tensile strength test were performed and test results were used to construct ANN model. A total of 131 values was used for modeling ANN, 80% in the training phase, and 20% in the testing phase. To construct the model, 25 input parameters were used to achieve one output parameter, referred to as the tensile strength of concrete containing partly pozzolanic materials and manufactured sand. The results obtained in both, the training and testing phases strongly show the potential use of ANN to predict 28 days tensile strength of concretes containing partly pozzolanic materials and manufactured sand.

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1. Introduction

As construction projects are growing day by day, they are utilizing the available sources of natural sand. This haphazard excavation of river beds for natural sand has created some environmental problems. Thus use of manufactured sand has become essential taking precaution of environmental and economical balance (Magudeaswaran et al., 2016). Also the production of huge quantities of cement requires large amount of energy, cause emission of CO2 and carry forward the allied problems. Therefore researchers are concentrating on finding out the supplementary cementitious materials such as fly ash, blast furnace slag, silica fume, metakaolin and rice husk ash which have shown promising results to replace cement partially (Mouli, 2008). The pozzolanic materials and manufactured sand are mostly used in the various huge projects. In order to improve these studies, reducing the amount of material, testing, time and cost, models based on experimental data can predict with an acceptable error range (Dantas et al., 2013). ANN model is a powerful tool that gives viable solutions to problems which are difficult to solve by through conventional techniques such as multiple regression models, not invalidating these existing techniques (Safiuddin et al., 2016).

2. Literature Review and Research Objective

Boukhatem et al. (2017) worked on the combined application of two different techniques, Neural Networks (NN) and principal components analysis (PCA) for improved prediction of concrete properties. The results

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showed that the elimination of the correlation between the input parameter using PCA improved the predictive generalization performance model with smaller architectures and dimensionality reduction.

Goyal et al. (2017) have studied compressive strength for three types of mix designs namely, M15, M20 and M25 is predicted using artificial neural network. The data is collected during the construction of main dam of Rajghar medium irrigation project located at Bhiwani Mandi in Jhalawar district of Rajasthan. Concluded that artificial neural network can be used to predict compressive strength of concrete.

Ashrafi et al. (2017) has used neural network technique to predict the strength of concrete based on mix proportions. He concluded that compressive strength trends are predicted by back propagation method in neural network.

Khademi and Behfarnia (2017) have studied the two different data-driven models, artificial neural network (ANN) and multiple linear regression (MLR) models. They have been developed to predict the 28 day compressive strength of concrete. And concluded that the multiple linear regression model is better to be used for preliminary mix design of concrete, and artificial neural network model is recommended in the mix design optimization and in the case of higher accuracy requirements.

Sayed-Ahmed (2012) has developed statistical model to predict the compressive strength of concrete containing different matrix mixtures at fixed age. The study reveals that the results from the predicted model have high correlation to the experimental results for the concrete compressive strength.

Khademi et al. (2016) have studied the three different data driven models Artificial neural network (ANN), Adaptive Neuro-Fuzzy inference system (ANFIS) and Multiple liner regression (MLR) were used to predict the 28 days compressive strength of recycled aggregate concrete. And conclude that the MLR models is better to be utilized for preliminary mix design of concrete. And ANN and ANFIS models are suggested to be used in mix design optimization and in the case of high accuracy necessities. Agrawal and Sharma (2010) has studied possible applicability of neural networks (NN) to predict the slump in high strength concrete (HSC). Concluded that the neural network model is most versatile to predict the slump in concrete.

Vignesh et al. (2016) have studied the back propagation method for the prediction of compressive strength of concrete .Concluded that ANN model have strong capacity for prediction of strength of concrete. Sonebi et al. (2016) have developed the neural network model for prediction of fresh properties of concrete and concluded that ANN performed well and provided very good correlation coefficients. The results show that the ANN model can predict accurately the fresh properties of SCC.

Najigivi et al. (2013) have developed two-layer feed-forward neural network was constructed. Study reveals that the novel developed neural network model (NNM) with three outputs will be a useful tool in the study of the permeability properties of ternary blended concrete.

The objective of this study is to evaluate the potential of artificial neural networks to concatenate a large amount of experimental data obtained from experimentation and predict the tensile strength of concrete containing pozzolanic materials and manufactured sand.

3. Artificial Neural Networks (ANN)

Artificial Neural Network (ANN) is a soft computing technique involving an input layer, one or more hidden layer and an output layer. The hidden layer is linked to the other layers by weights, biases and transfer functions. An error function is determined by the difference between network output and the target. The error is propagated back and the weight and biases are adjusted using some optimization technique which minimizes the error. The entire process called training is repeated for number of epochs till the desired accuracy in output is achieved. Once the network is trained it can be used to validate against unseen data using trained weights and biases (Sayed-Ahmed, 2012, Khademi et al., 2016).

4. Data

By referring Indian standard IS 5816-1999 (IS: 5816-1999) the tensile strength test on cylinder 150mm diameter and 300 mm length was conducted. The photograph of tensile strength test shown in Fig. 1, Eq. (1) was used for calculation of tensile strength:

$$\text{Tensile strength} = \frac{2\times P}{\pi\times L\times D} \quad (1)$$

where: P = failure load applied to the cylinder (N); L = cylinder length (mm), D = cylinder diameter (mm).

Mandatory input parameters as per standard mix design procedures followed all over the world following parameters were treated as mandatory parameters in concrete mix design. The parameters were cement (C), natural sand (N.S), Manufactured sand (MS), Coarse aggregates (C.A), Fly ash (F.A), Silica fume (S.F.), GGBFS, metakaolin (Meta.). These input parameters remained same for all the networks. The maximum and minimum values of input and output parameters are shown in Table 1. A total of 131 values are available in which all values were obtained from fresh experimentation (Vignesh et al., 2016). For ANN model three layered "Feed forward Back propagation" network was developed to predict the 28 day tensile strength of concrete and trained till a very low performance error (mean squared error) was achieved. The numbers of neurons in hidden layer were decided by trial and error. All the networks were trained using Levernberg-Marquardt algorithm with 'log-sigmoid 'transfer functions in between first (input) and second (hidden) layer and 'linear' transfer function between the second and third layer (output).The data was normalized between 0 to 1. From the available data 80% of data was used for training, 20% for validation and testing (Khademi et al., 2016; Vignesh et al., 2016).

Table 1. Input and output parameters.

Sr. no.	Input parameter	Range of values	
		Minimum	Maximum
1	Cement content (C) kg/m^3	337.77	422.22
2	Natural sand content (N.S) kg/m^3	0	612.21
3	Manufactured sand content(M.S.) kg/m^3	0	612.21
4	Course aggregate content (C.A.) kg/m^3	-	1258.21
5	Fly ash content (F.A.) kg/m^3	0	84.85
6	Silica fume content (S.F.) kg/m^3	0	84.85
7	GGBFS content kg/m^3	0	84.85
8	Metakaolin content (Meta.) kg/m^3	0	84.85
	Output parameters		
1	Tensile strength (MPa)	3.73	4.72

Fig. 1. Tensile strength test.

Instead of using single experimentation for each combination of material, we are using different (5 types) of combinations at a time as an input data while training the neural network and hence it shows 25 input layer models as detailed in Fig. 2. The maximum number of hidden layers value is set to 30 out of which neural network consumes as per the requirement and here we can see that maximum 10 hidden layers are used during the experimentation. The target values set which are actual desired results with respect to practical experimentation values are to be achieved in maximum 10,000 iterations with convergence target to be 1e^{-25}.

The learning rate is set to 0.01 with step 0.01 as α and μ values of the network respectively. The entire configuration of the network is set and can be understood from the Table 2.

Table 2. Neural network configuration parameters.

Parameter	Configuration value
Input layers	25
Hidden layer	10
Output layer	1
Convergence	1e^{-25}
Learning rate (α)	0.01
Step size (μ)	0.01

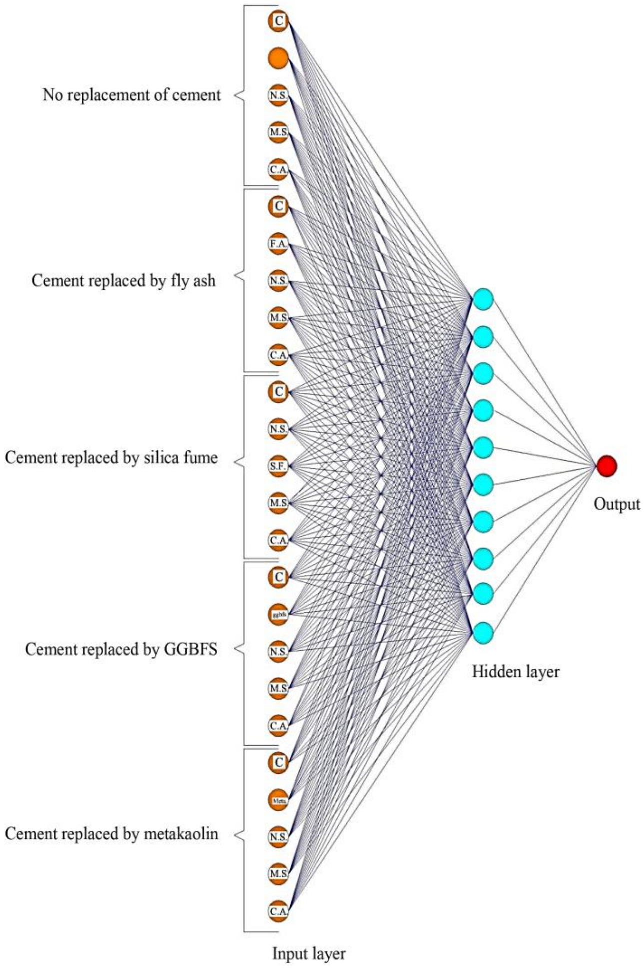

Fig. 2. Neural network layered structure.

5. Results and Discussion

The experimental and predicted tensile strength values for different replacement of natural sand by manufactured sand and 20% cement replaced with fly ash, silica fume, GGBFS and metakaolin in concrete are shown in Table 3. The variation of experimental and predicted tensile strength values are shown in Figs. 3 to 7. It is observed that experimental and predicted tensile strength values are very near to each other. The percentage variation for this model was not increase over 2.93% for no replacement of cement, 0.93% for cement replaced with fly ash. 1.14% for cement replaced with silica fume, 1.94% for cement replaced with GGBFS and 0.88 % for cement replaced with metakaolin which is acceptable variation. It is also observes that correlation coefficients have values between +1 and -1. A correlation coefficient of +1 indicates perfect positive correlation and coefficient of -1 indicates a perfect negative correlation. The correlation coefficient (R) for training, testing, validation and overall data is illustrated in Table 3. The total value of R square for training, validation and test is 0.941 for no replacement, 0.980 for cement replaced with fly ash, 0.979 for cement replaced with silica fume, 0.906 for cement replaced with GGBFS and 0.957 for cement replaced with metakaolin which is satisfactory. R^2 value is a statistical measure of how close the data are to the fitted in regression line (Ni and Wang, 2000; Reddy, 2018; Islam et al., 2012). In all the figures the model presents good results in the case of R values. Results from establishing an artificial neural network illustrates a good degree of coherency between the target and output values. Therefore, using ANN model, the 28 days tensile strength of concrete can be predicted accurately.

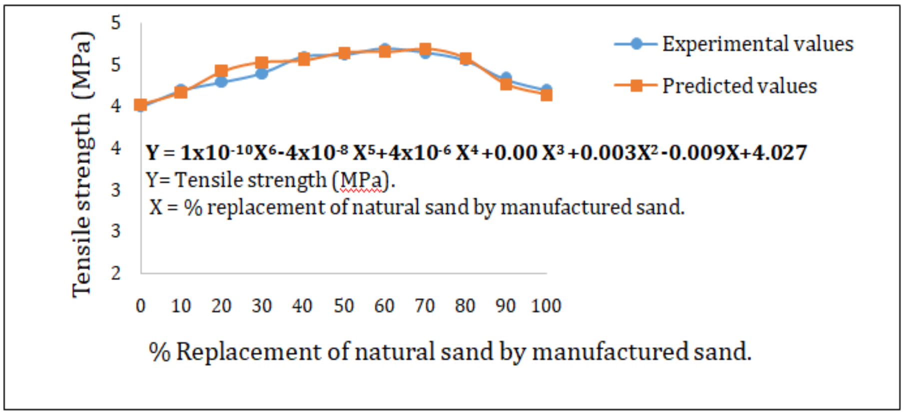

Fig. 3. Variation of predicted and experimental tensile strength for no pozzolans.

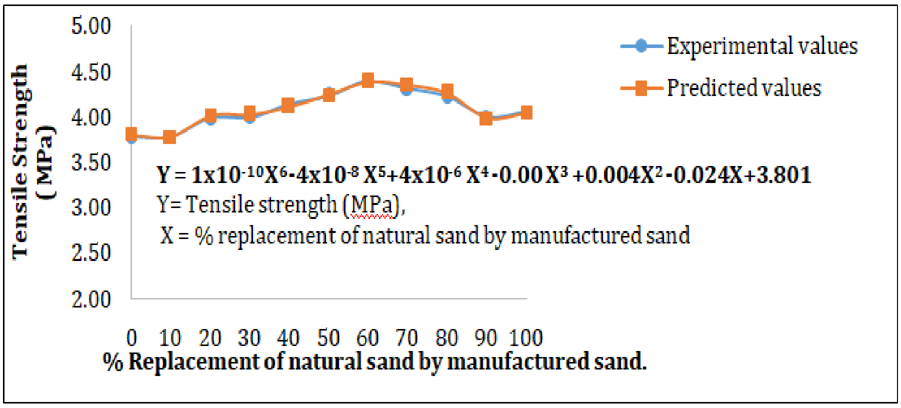

Fig. 4. Variation of predicted and experimental tensile strength for partly replacing cement by FA (fly ash).

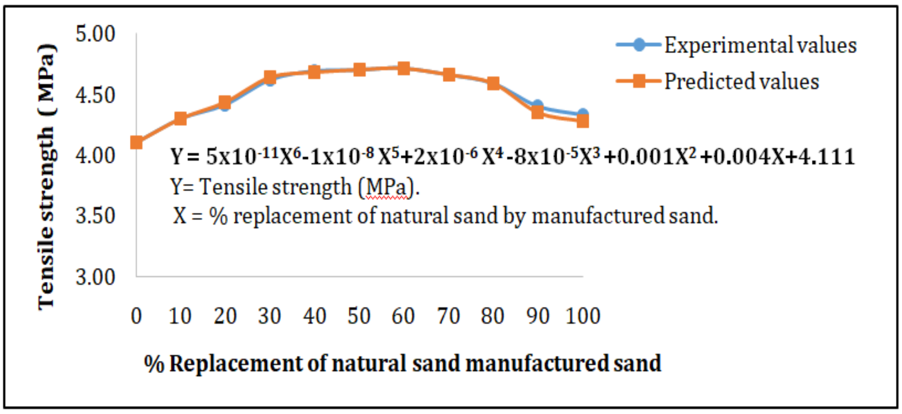

Fig. 5. Variation of predicted and experimental tensile strength for partly replacing cement by SF (silica fume).

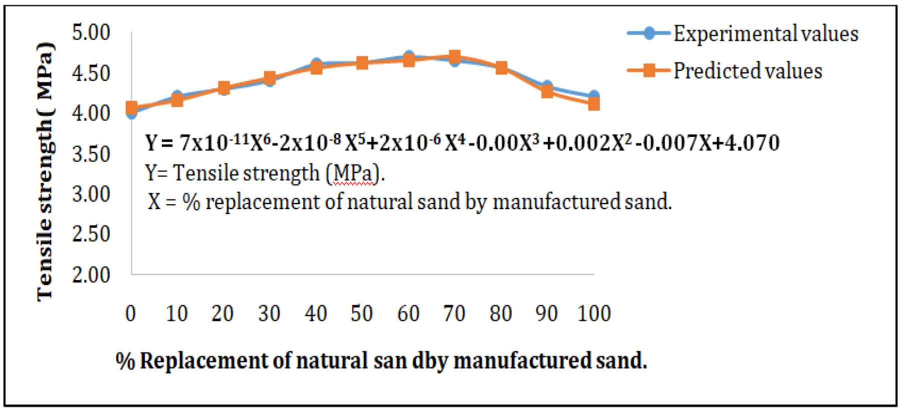

Fig. 6. Variation of predicted and experimental tensile strength for partly replacing cement by GGBFS.

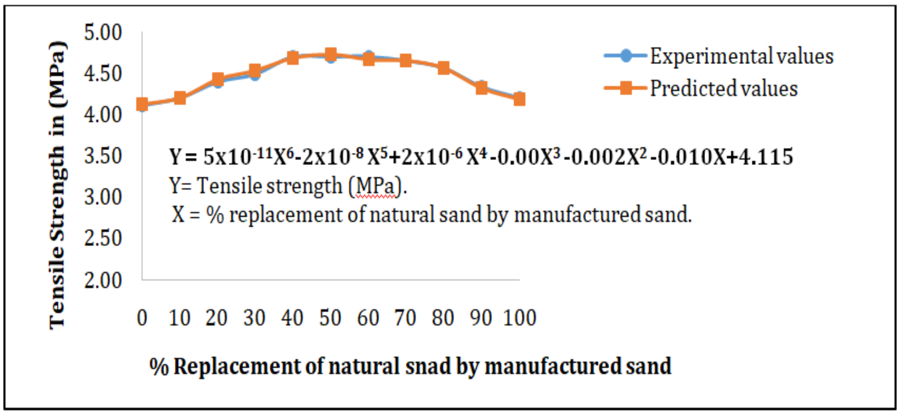

Fig. 7. Variation of predicted and experimental tensile strength for partly replacing cement by metakaolin.

Table 3. Overall experimental and predicted tensile strength (MPa) values.

Percentage replacement of natural sand by manufactured sand	Tensile strength (MPa) values									
	No replacement of cement		Cement replaced by fly ash		Cement replaced by silica flume		Cement replaced by GGBFS		Cement replaced by metakaolin	
	R^2 = 0.941		R^2 = 0.980		R^2 = 0.979		R^2 = 0.906		R^2 = 0.957	
	Experimental	Predicted	Experimental	Predicted	Experimental	Predicted	Experimental	Predicted	Experimental	Predicted
0	3.73	3.75	3.78	3.81	4.10	4.11	4.00	4.07	4.10	4.12
10	3.74	3.71	3.78	3.78	4.30	4.30	4.20	4.16	4.20	4.20
20	3.95	4.06	3.98	4.01	4.42	4.43	4.30	4.31	4.40	4.43
30	3.98	4.09	3.99	4.03	4.62	4.64	4.40	4.43	4.49	4.53
40	4.1	4.05	4.14	4.11	4.69	4.69	4.60	4.55	4.69	4.69
50	4.21	4.23	4.23	4.24	4.70	4.71	4.62	4.62	4.69	4.73
60	4.35	4.31	4.39	4.39	4.72	4.72	4.70	4.65	4.70	4.66
70	3.65	3.68	4.31	4.35	4.66	4.66	4.65	4.70	4.65	4.65
80	3.53	3.54	4.22	4.26	4.59	4.59	4.56	4.56	4.56	4.57
90	3.37	3.32	4.00	3.98	4.40	4.35	4.33	4.27	4.33	4.31
100	3.35	3.30	4.05	4.04	4.33	4.29	4.20	4.12	4.20	4.19
	Max. variation = 2.91%		Max. variation = 0.93%		Max. variation = 1.14%		Max. variation = 1.94%		Max. variation = 0.88%	

The grading curve of natural sand and manufactured sand are shown in Fig. 8 and fineness modulus for each replacement of natural sand and manufactured sand are given in Table 4. It is clearly observed that the concrete made by using no replacement of natural sand by manufactured sand and no pozzolans with fineness modulus 2.81 shows lesser experimental and predicted tensile strength values. Up to 60% replacement the experimental and predicted tensile strength values and fineness modulus values go on increasing after that the experimental and predicted tensile strength values go on reducing. From this observation it is clear that, at 60 % replacement with fineness modulus 2.87, experimental and predicted tensile strength values are high. The same observation are noted for concrete made by partly replacing cement with fly ash or metakaolin or GGBFS or silica fume. The reason behind this at 60% replacement of natural fine aggregate by manufactured sand shows very compactable concrete with less voids and optimal particle size distribution resulting strong experimental and predicted tensile strength (Yalley and Sam, 2018).

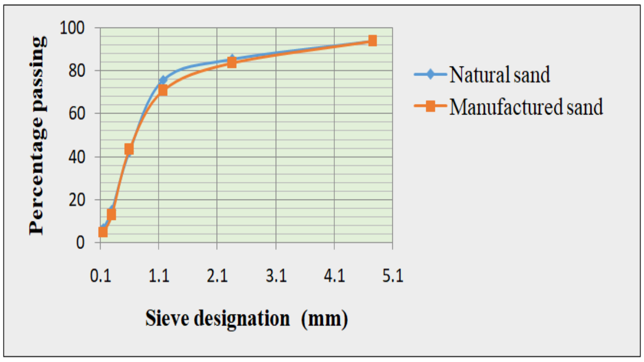

Fig. 8. Grading curve for natural and manufactured sand.

Table 4. Fineness modulus of each replacement of natural sand to manufactured sand.

% Replacement of natural sand by manufactured sand	Fineness modules
0%	2.81
10%	2.83
20%	2.84
30%	2.85
40%	2.85
50%	2.86
60%	2.87
70%	2.88
80%	2.89
90%	2.89
100%	2.91

6. Conclusions

- The model is used successfully for predicting the tensile strength of concrete. The test of the model by input parameters shows acceptable maximum percentage of error.
- The ANN model may be used successfully for predicting the tensile strength of concrete. On any construction site fast tensile strength is required but minimum 28 day are required to find tensile strength. The produced ANN model predict fast strength in very short time so there is no need to wait for 28 days. So ANN model is capable to predict 28 days tensile strength.
- ANN model were found to be efficient in predicting the 28 days tensile strength.
- At fineness modulus 2.87, experimental and predicted tensile strength values are high.

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Research Article

Investigation of some engineering properties of waste polytetrafluoroethylene (PTFE) fiber reinforced concrete

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ABSTRACT

In this study, a comparison was made between concrete with waste PTFE fiber and standard concrete. Both elastomeric and thermoplastic fluoropolymer find a wide use especially in automotive applications such as seals, pulley etc. A large amount of PTFE occurs during this applications production. PTFE fiber is not a conventional concrete additive. It is a waste material and it can be used as a concrete filler material. In order to investigate the behaviour of this waste material in the concrete, mixtures containing waste PTFE fiber in amounts of 25%, 50%, 75%, and 100% (by weight) in order to replace to the same amount of fine sand (0-1 mm) were prepared. The compressive strength, tensile strength, workability and unit weight of the waste PTFE fiber concrete investigated. It was observed that waste PTFE fiber concretes have sufficient strength to be used as semi structural concrete. The mechanical behaviours of waste PTFE fiber concrete and control concrete were very similar. Moreover, it was observed that the unit weight and workability of the waste PTFE fiber concretes were decreased. This study provides that reusing waste PTFE fiber as an artificial filler material in concrete gives a new approach to solve some of the solid waste problems by plastics.

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1. Introduction

The aggregate in concrete occupies about 70 percent of the volume, it is frequently looked upon as an inert filler and therefore not worthy of much attention concerning its possible influence on the mechanical properties of concrete. The most important mechanical properties of concrete are compressive and tensile strength. The ordinary portland cement concrete, which is designed based on compressive strength, does not meet many functional requirements as it is found deficit in aggressive environments, energy absorption capacity, time of construction, repair and retrofitting jobs (Patel and Shah, 2013). Therefore, there is a need to make fiber aggregates concrete, which is more durable to the conventional concrete as the ingredients of fiber aggregates concrete supply most efficiently to the various properties. A waste or synthetic aggregates are being increasingly used in concrete instead of natural sand and coarse aggregate. Recently, many studies have been done on fiber concrete. One of them is " The Mechanical and Tribological Properties of PTFE Filled with PTFE Waste Powders" by Xiang and Tao (2006). And the other is "Concrete Containing Polyester Fibers" by Gurunandan et al. (2018). Utilization of industrial plastic wastes in construction industry investigated for many years. In countries where abundant industrial plastic wastes are discharged, these wastes can be used as potential material or replacement material in construction industry. It as an inert filler in concrete.

Experimental studies showed that fibers improve the mechanical properties of concrete such as flexural strength, compressive strength, tensile strength, creep behaviour, impact resistance and toughness (Topcu and Canbaz, 2007). Since the concrete is a brittle material, its tensile strength is low. Reinforcement is used to increase the low tensile strength. Normally, the reinforcement consists of plain steel bars, usually with circle sections.

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Recently, there has been an increasing interest in several types of micro reinforcement as alternatives. Fibers can be metallic, mineral, natural, or synthetic organic (for instance, polypropylene and Polytetrafluoroethylene). The fibers can be mixed with concrete or can be sprayed onto the concrete surface. New types of fibers, new methods of fabrication and different types of applications are continuously being developed (Shah, 1981). For example, Liu et al. (2011), studied characterization of fiber distribution in steel reinforced cementitious composites with low water-binder ratio. They have found that the aggregate characteristics have significant effect on fiber distribution, with increase of aggregate size.

Today, many researchers are looking for materials that can replace aggregates in their fiber concrete experiments. In many developed countries, because of the increasing cost of natural fillers and the continuous reduction of natural resources, the use of waste materials is an alternative for making concrete. Waste materials, when properly processed, have shown to be effective as construction materials and readily meet the design specifications. Mannan et al. (2004) studied structural lightweight concrete has been produced using oil palm shells as aggregates in concrete. Kan and Demirboğa (2009a), pointed out the economic and environmental benefits to be gained from waste recycling are very big, since it will benefit both the environment and the construction industry in terms of cost reduction. Using the modified expanded polystyrene (MEPS) as aggregates for concrete, they have found that the new material improves some of the concrete properties and at the same time, it had negative effects to some of its properties. In addition, they found that by using a high amount of MEPS as aggregate, it had decreased the density of concrete. However, from an environmental perspective, using the waste MPES foams is very significant. While there is important research on many different materials for aggregate substitutes, such as coal ash (Nisnevich et al., 2006), blast furnace slag (Topcu and Boğa, 2010) or various solid wastes including glass (Park et al., 2004), expanded and modified polystyrene foams (Kan and Demirboğa, 2009b), paper and wood wastes (Elinwa and Mahmood, 2002). The only two that have been significantly applied waste glass and modified waste expanded polystyrene concrete. Bayasi and Zeng (1993) studied the effects of polypropylene (PP) fibers on the slump and inverted slump cone time of concrete mixes. Al-Manaseer and Dalal (1997), determined the slump of concrete mixes made with plastic aggregates. They reported that when using plastic aggregate instead of normal aggregate in concrete mix, the value of slump increases. The aim of the researches were to investigate some of the physical and mechanical properties of a laboratory-produced concrete to which had been added varying proportions of waste materials as aggregate. Initial experiments carried out to characterize the waste recycled aggregate and its suitability as concrete aggregate. It was concluded that the use of recycled aggregates in concrete usually have changed the concrete properties.

Tam and Tam (2006) stated that technology is being developed that will enable building materials to be progressively infused with recycled plastic constituent in order to increase strength, durability and impact resistance, and enhance appearance. Pezzi et al. (2006) used plastic material particles incorporated as aggregate in concrete and evaluated the chemical, physical, and mechanical properties. The results showed that the addition of polymeric materials in proportion less than 10% in volume inside of a cement matrix does not imply a significant variation of the concrete mechanical characteristics. Researchers observed that if waste materials were segregated into degradable and non-degradable at the source, then it was easier to control environmental pollution. Waste PTFE is non-degradable material at the source.

PTFE finds an exceptional position in plastic industry due to its excellent chemical properties and heat resistance, electrical insulation and its significantly low friction coefficient. These properties recommend PTFE for numerous applications. Both elastomeric and thermoplastic fluoropolymer find a wide use especially in automotive applications such as seals, pulley etc. It also blended with other polymers as a composite material for special purpose applications (Khan et al., 2008). A large amount of PTFE occurs during this applications production.

In other words, during Teflon© material process occurs PTFE shaving. (Teflon is the commercial name of polytetrafluoroethylene polymer. Teflon is a polytetrafluoroethylene with fluorinated ethylene polymer. It was discovered by Roy J. Plunkett in 1938 in Du Pont and was commercialized in 1946.) That shaving is long and continuous and can reach lengths of 10 or 20 meters Waste PTFE fibers present non-regular cross sectional geometry, which enhances their bond characteristics. This waste is not recycled in any form at present. The amount of plastic waste materials generated increases each year. The waste PTFE shaving is one of the industrial plastic wastes, produced in large quantity has the potential to be used as fiber in concrete (Fig. 1).

Fig. 1. Waste PTFE shavings.

2. Materials

The waste PTFE fibers, we used in the experiments have obtained from a company producing PTFE seals in the industry. When producing PTFE seals in this factory, quite a lot of waste PTFE fibers are released. In general, this acquisition method of PTFE waste fibers is called the conventional method. In this study used to the conventional method for the production of waste PTFE fiber. The generally description of this process is shown in Fig. 2. Conventional methods of particle size reduction include milling, grinding, jet milling, crushing, and air micronization. Detailed descriptions about the materials used, specimens tested and testing methods are essentials for an experimental investigation. The general properties of the PTFE fibers appear in Table 1.

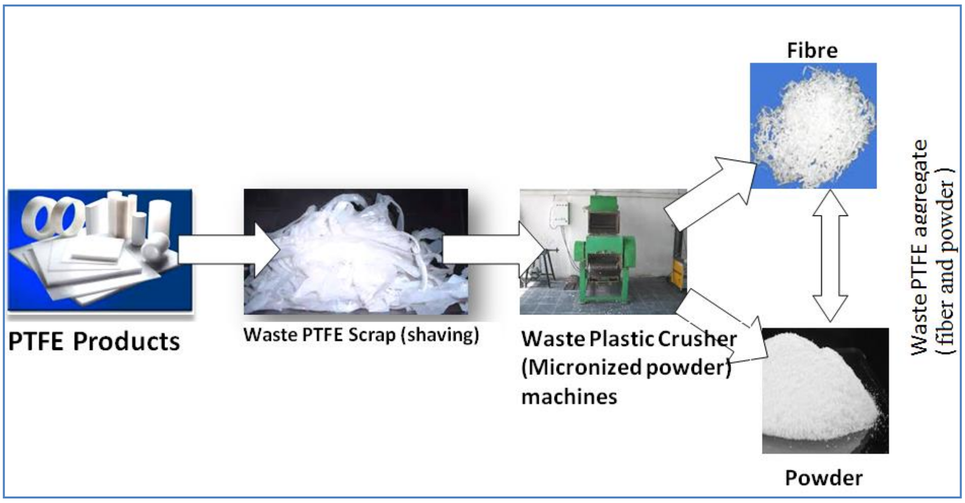

Fig. 2. Description of the process of waste PTFE aggregates.

Table 1. General specification of PTFE fiber.

Specifications of waste PTFE fiber	
Particle sizes and thickness	0.54-6.00 mm
Colours	White
Containing water scale	≤0.04%
Melting point	≥279 – 326°C
Standard relative density	2.15 - 2.17 kg/*l* *(2.10)*
Tensile Strength (MPa)	14 to 38
Compressive Strength (MPa)	24
Thermal conductivity	0.25 W/(m·K)
Water Absorption, 24 hrs (%)	< 0.01
TEFLON ® is a registered trademark of DuPont	

3. Methods

The materials used for the both control concrete and PTFE fiber concrete consisted of the normal Type I Portland cement. The control concrete has coarse aggregate having a maximum size of 16 mm, and fine aggregate was river sand with a maximum grain size 4 mm and a moisture content of 1.40%.

In this mixture, we did not want to have a fine aggregate within the range of 0-1 mm. This size of the aggregate adheres to the surface of the naturally slippery PTFE fiber, and its making even more slippery.

For the normal concretes, the fine aggregate were classified according to their aggregate sizes of (cumulative percentage passing) 0-0.25 (4%), 0.25-0.5 (16%), 0.5-1.0 (32%), 1.0-2.0 (43%), and 2-4 mm (65%). Coarse aggregate were classified 4-8 (57%) and 8-16 mm (43%). Fineness moduli of fine aggregate mixture (by weight) were 3.61. Sands having fineness moduli of 2.5. The specific gravity of sand aggregate (0–4 mm) is 2650 kg/m^3, and the specific gravity of coarse aggregate (4–16 mm) is 2700 kg/m^3. The unit weight of sand aggregate (0–4 mm) is 1650 kg/m^3, and the unit weight of coarse aggregate is (4–16 mm) 1480 kg/m^3.The grain size distribution and the grading curves of the PTFE concrete natural aggregates are shown in Table 2 and Fig. 3, respectively.

Control concrete and various PTFE fiber contents as listed in Table 3. All concretes of C25 grade was designed as per the procedure given in BS and ASTM codes. Concrete was mixed in a tilting type drum mixer and the specimens were cast as per the recommendations of codes.

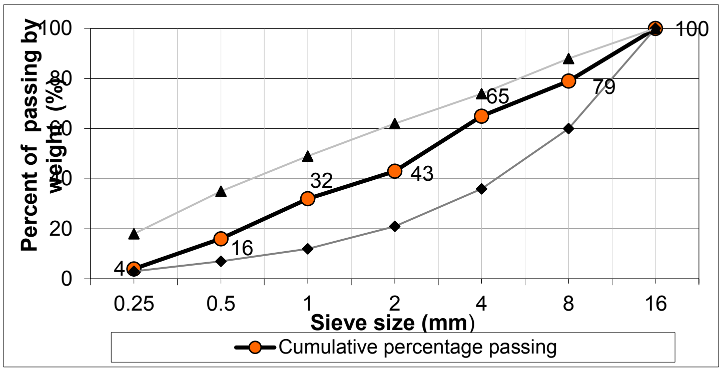

Fig. 3. Grain size distributions of the aggregate (0-16).

Table 2. Grain size distribution of the aggregate (0-16).

Sieve size (mm)	Cumulative percentage passing (%)
16.00	100.00
8.00	79.00
4.00	65.00
2.00	43.00
1.00	32.00
0.50	16.00
0.25	4.00

Approximately 300 kg/m^3 of cement and 110-130 l/m^3 of mixing water were used with 518 kg/m^3 coarse aggregate and 1390 kg/m^3 (598 kg/m^3 for 0-1mm, 792 kg/m^3 for 1-4mm) sand for the nonfibrous concrete mixture. PTFE fiber has replaced fine sand (0-1 mm) by weight. The percentages of PTFE fiber within the fine sand aggregate were 0, 25, 50, 75, and 100% by weight. Concrete placed uniformly over the length of the mould in three layers and compacted satisfactorily. Once the samples were moulded, known processes were performed. With tests on hardened concrete unit weight, cylindrical compressive, strength was determined. Table 3 shows the mix proportions by weight of the mixture. On the fresh concretes the unit weight and slump tests were carried out, then 30 (Three samples for each percentage of PTFE mixing) standard steel moulds were used for casting of cylinders of 100 mm diameter and 200 mm height, were prepared. In this study, split tensile strength test was conducted on 100 mm diameter 200 mm cylinders at 28 days as per ASTM C 496-89. In splitting tensile test, as seen Fig. 4, a concrete cylinder, of the type used for compression tests, is placed with its axis horizontal between the platens of a testing machine, and the load is increased until failure by indirect tension in the form of splitting along the vertical axis takes place.

Table 3. Details of raw and fresh concrete containing waste PTFE fiber.

Mix Number		1*	C1	C2	C3	C4
Cement (kg/m^3)		300	300	300	300	300
W/C		0.45	0.45	0.43	0.43	0.42
% Vol. of waste PTFE fiber		0	25	50	75	100
Waste PTFE fiber (kg/m^3)		0	150	300	450	600
Sand (fine aggregate) (kg/m^3)	0-1mm	598	448	300	150	0
	1-4 mm	792	790	782	748	712
Total fine aggregate (kg/m^3) (PTFE+FA)		1390	1388	1380	1346	1310
Coarse aggregate (kg/m^3)		518	518	518	518	518
Net mix Water (*l*/m^3)		130	121	119	117	110
Raw Concrete Unit Weight (kg/m^3)		2338	2327	2317	2281	2238
Fresh Concrete Unit Weight (kg/m^3)		2330	2320	2300	2273	2212
Amount of entrapped air %		2	2.5	3	3.5	4
Slump (mm)		40	50	55	60	70

* Control samples

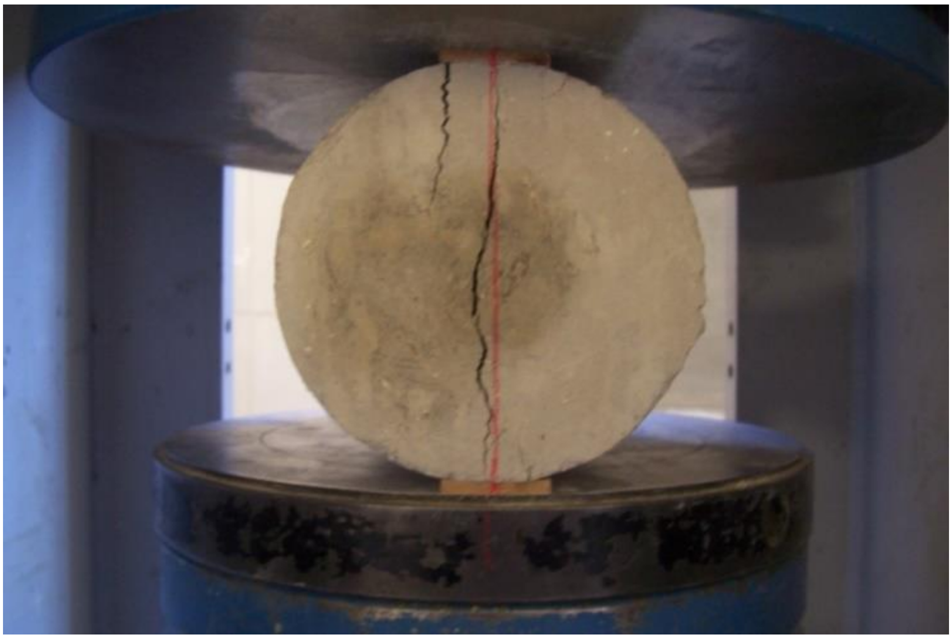

Fig. 4. Splitting tensile strength cylinder test.

4. Results and Discussion

After the experiments conducted on series of fresh and hardened concrete, properties for workability and strength were determined. Each sample was disassembled after testing to examine whether any segregation had occurred during compaction or testing. No significant migration of waste PTFE fibers was seen for any of the mixed specimens. It has made the compaction and consolidation of the concrete specimens into moulds easier.

4.1. Effects of PTFE fibers on unit weight

A lighter material than sand is added into the concrete in the place of sand, so the unit weight of concrete decreased. This is an expected situation. (The density of PTFE is about 2.1-2.2, but the density of sand is 2.6) Mix 1* contains only natural aggregate while corresponding Mixes C1 to C4 contains PTFE sand as the fine (0-1 mm) aggregate. The mix proportions of the Mixes 1* (Control samples) and C1 are nearly the same.

As the waste PTFE fiber aggregate ratio increases, concrete density decreases. With using natural fine sand in concretes allows decreasing the unit weight from 2330 kg/m^3 to 2212 kg/m^3. On the other hand, PTFE having ratio of 50% and 75% allows further decrease in unit weight. PTFE is not property of the water absorption, all of the mixing water used by the cement and aggregates. Changes in the unit weight depending on the PTFE aggregate ratio were examined.

4.2. Effects of PTFE fibers on workability

Workability of concrete is defined as the ease with concrete can be mixed transported placed and finished easily without segregation. In the research on concrete mixtures including PTFE fiber, it is seen that slump values increase whereby the PTFE fiber increases. The slump value is 40 mm if there is no PTFE fiber in it (control samples). If there is then the slump value is 70 mm (having 100% PTFE fiber instead of sand). The most important reason for this is that PTFE fiber has not a high absorption ratio. Plastic aggregates neither absorbed nor added any water to the concrete mix. Due to this, non-absorptive characteristic concrete mixes containing plastic aggregates will have more free water. Consequently, the slump increased. As well as PTFE is slippery. The amount of water required to the mixture decreased by increasing the amount of PTFE. Additional research has been done on the unit weights of the fresh concretes. Although the measured fresh density is 2330 kg/m^3 in normal concrete. The fresh density is 2212 kg/m^3 in concrete including 100% PTFE fiber. This decline is directly connected with the fact that the density of the PTFE fiber is the same as the normal aggregate.

PTFE fibers does not absorb any liquıd. Additional water is no added as a content of the PTFE fiber concretes. Thereby bringing the total water: cement ratio up to the order to 0.42-0.45. In general, when the amount of PTFE fiber was increased as for lighter densities the amount of water can therefore be decreased. In fresh concrete air content is relatively higher in PTFE concrete than normal concrete. PTFE fibers come in many shapes such as stripe or chips small fiber and other irregular shapes as shown in Fig. 1. And these obstruct in achieving full compaction of PTFE concrete. In addition, as can be seen from Table 3. Due to the amount of water required for wetting surfaces of the PTFE, material increased the amount of mixing water.

4.3. Effects of PTFE fibers on compressive strength

A comparison of the strength results of these two sets of mixes having comparable densities clearly shows that the effect of PTFE is negligible, both in terms of the strength gain rate as well as the strength at 28 days. However, it was observed that the mixes containing PTFE aggregates always show a slight decrease in density. The compressive strength decreased with the addition of PTFE to a mixed specimen. Using 0% PTFE in the control mix increased the compressive strength of the concretes (27 MPa at 28 days). However, further increasing in PTFE content caused reduction in compressive strength.

The 28-day cylinder compressive strength of the resulting, having 100% PTFE aggregate concrete with unit weight of 2212 kg/m^3 and respective strength of 18.20 MPa. The variation of compressive strength with the unit weight of concrete (and percent weight of PTFE) was presented in Table 4 and Fig. 5. As shown in Table 4, compressive strength decreasing with increasing unit weight because of the increasing ratio of PTFE. At the end of the unit weight tests on the hardened concretes, it was seen that unit weight increases when the PTFE increases.

It can be seen that the addition of PTFE causes a significant decreasing in the compressive strength. The waste PTFE fibers play an important role in decreasing compressive strength (up to 33%). In particular, C4 mix (have 100% PTFE) exhibited the minimum compressive strength which more than likely is due to the presence of the PTFE fibers. When the waste PTFE fibers were added to mix, there was practically a slight decrease in the compressive strength of PTFE concretes. The compressive strength of the PTFE concretes is reduced significantly with an increase in the PTFE cement ratio due to the insufficient film formation. In general, the compressive strength of the PTFE concretes is low because of the insufficient strength development of cement matrix.

4.4. Effects of PTFE fibers on splitting tensile strength

The obtained splitting tensile strengths after 7 and 28 days are presented in Table 4. Each value is the average of three measurements. Fig. 6 shows that the splitting tensile strength tends to decrease with the increases of the percentage of waste PTFE replacement in the concrete mixture compared with the control mixes. According to the test results, the 28 days splitting tensile strength values are observed to decrease. The surfaces of the Teflon fibers are smooth. It does not stick because it is naturally lubricated. Therefore PTFE fibers having a low coefficient of friction. It can be easily pull out from concrete.

Table 4. Compressing strengths and splitting tensile strengths and unit weights of PTFE fiber concretes.

Mix Specification		Control mix	C1	C2	C3	C4
Proportion of PTFE (amount of fine sand)		0%	25%	50%	75%	100%
Compressing strength	7 days	23.00	22.80	19.25	18.20	17.00
	28 days	27.00	26.30	22.00	20.00	18.20
Splitting tensile strengths	7 days	2.53	2.51	2.30	1.95	1.70
	28 days	2.81	2.75	2.65	2.50	2.40
Fresh concrete density (kg/m^3)		2330	2320	2300	2273	2212

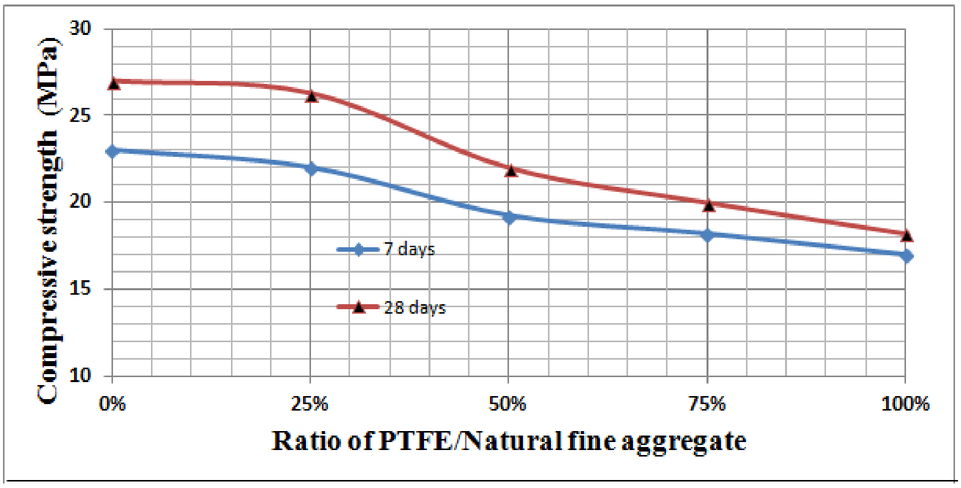

Fig. 5. Relationship between compressive strength and PTFE fiber at 7 and 28 days.

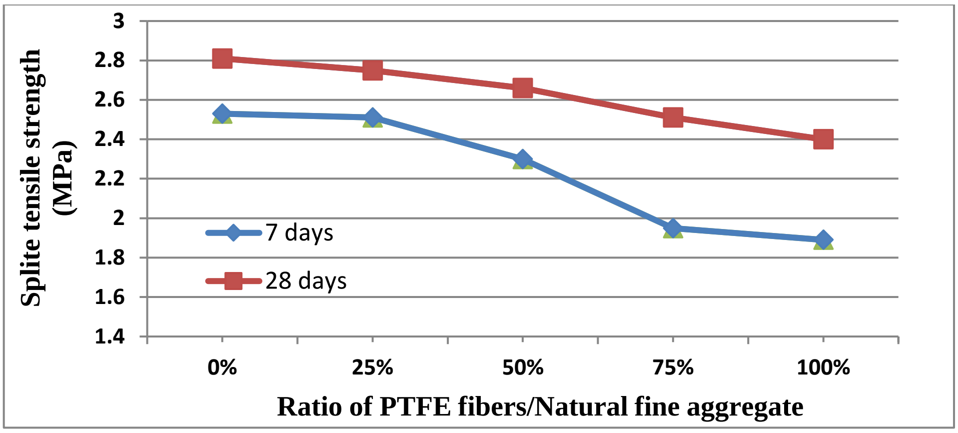

Fig. 6. Relationship between splitting tensile strength and % of replacement of waste PTFE at 7 and 28 days.

5. Conclusions

The test results showed that the waste PTFE fiber might be used as a filler substitute in concrete. Use of waste materials and by products not only helps in getting them utilized in cement concrete and other construction materials. It helps in reducing the cost of cement and concrete manufacturing but also has numerous indirect benefits such as reduction in landfill cost saving in energy and protecting the environment from possible pollution effects.

PTFE fiber reinforced concrete is typically used in nonload-bearing applications particularly where impact resistance is important. The use of PTFE fibers for control of cracking in slabs are still being debated due to the amount of fibers required to positively affect the amount of cracking and the subsequent effect on workability. The characterization of PTFE fiber wastes revealed that it is a valuable material with little variability of characteristics and that its recovery for semi structural concrete is possible. Proved the inclusion of PTFE fiber wastes in cement matrix does not change the rheological behaviour characteristic for concrete.

Due to the geometry of PTFE fibers, a homogenous distribution of fibers could not be achieved. Because these fibers are dispersed randomly in concrete mixture. Accordingly, an increase of PTFE fibers used in concrete decreased compressive strength. Compressive and tensile strengths all decrease when adhesion is not fully achieved in the concrete containing PTFE fiber. Non-absorbent aggregates like waste PTFE do not suffer with the disadvantage of water absorption, which makes production of the concrete difficult.

In fact, when we decided to do this work, we did not expect much from the results. We wanted to contribute to the studies on waste assessment. Alternative systems using recycled materials contribute to environmental waste reduction and the development of sustainable products for the building industry.

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Review

Investigation of roller compacted concrete: Literature review

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ABSTRACT

Roller compacted concrete is a type of zero slump product produced from the same materials with conventional concrete. There are various methods for the design of RCC namely; corps of engineers' practice, high paste method, roller compacted dam method and maximum density method. Development of RCC has led a significant shift in the construction projects primarily in dams as the traditional practise of placing, compacting and consolidation is slow. By using RCC in earth and rock filled dams made the construction process quicker and consequently shortened the duration of construction. RCC used dam projects and be completed 1-2 years earlier than the other dams as mentioned in the article of Bagheri and Ghaemian (2004). Use of RCC has substantially increased in the last decades especially for pavement applications. It has a low construction cost and can be done quickly compared to asphalt. It is widely constructed in areas/ roads carrying heavy loads in low speed. On the other hand, in recent years' utilization of RCC in urban areas such as highways and streets has also increased. It has been proved that RCC has a competitive advantage over high performance asphalt pavements in terms of high compressive strength, durability, low maintenance cost, longer service life. Like conventional concrete, fibre addition is widely preferred in RCC as well. Fibre addition has contribution to mechanical properties of RCC and sustainability.

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1. Introduction

Roller compacted concrete (RCC) has been commonly used by many contractors in infrastructures, hydraulic structures and pavement applications as shown by Wang et al. (2018). In recent years RCC has become a highly preferred application especially in urban areas according to Williams (2014). RCC contains the same ingredients; well graded aggregates, cementitious materials, and water, just like conventional concrete. The main difference between RCC and traditional concrete is the mixture propositions. RCC is a zero-slum concrete that is placed with the help of a compactor, additionally vibratory rollers are also needed in the process to generate high strength and durability in the concrete. RCC contains a larger percentage of fine aggregates in comparison to standard concrete and this can be seen as the main difference from conventional concrete as stated by Jones (2012). This enables RCC to have tight packing and better consolidation (ACI 327, 2015). Amount of cement used in RCC mixture is also lower than typical Portland Cement Concrete. RCC contains 12% cementitious material by weight, while PCC has 15%. The type of cementitious material has a vital influence on the rate of hydration and strength development. Therefore, Type II Portland cement is widely preferred in RCC. It is noted that the quality of aggregate and water affect the strength of RCC (Luhr, 2000). RCC and conventional concrete comparison is given in Table 1.

RCC has been used for various purposes with different applications due to its simple applications. It is employed in container yards, dams, airports, logistical areas such as; freight terminals, logistic centre and highways. It is widely preferred to be used in highways as an alternative option to asphalt. When it is applied as highway or road pavements, the traffic can be opened reasonably in a short time (Mohammed, 2018). Therefore, it is a time saving application. Formwork, surface finishing, dowelled

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joints or reinforcement is not required for RCC. In this respect RCC can be considered as economical and fast (Berry and Tayabji, 2001).

This study aims to review the literature in terms of the content of RCC (both fibres added, and non-fibre added), utilisation of RCC, and advantages of its applications in the construction projects. Besides, within the scope of this study RCC is reviewed by considering 4 factors which are; environmental effect, cost, fibre addition, country basis RCC use. In this respect, this study is unique and provides useful data to the researchers.

Table 1. RCC comparison with conventional concrete (Hazaree, 2007).

Criteria	Conventional Concrete	RCC
Consistency	Slump test, flow test etc. (No Ve-Be test is required).	Determined by Ve-Be method.
Cement Content	Determined based on the water demand of the aggregate system and water to cement ratio	Generally, includes low cement contents
Moisture content	Determined by water to cement ratio (wt. %)	Determined by optimum water content
Aggregate gradation	Relatively less well graded	Well graded
Fresh concrete property determination	Slump and temperature-based methods.	Ve-Be consistency, optimum moisture content and maximum fresh (dry) density methods.
Spreading and laying	Slipping from paving machines, and/or manually	by a backhoe, loader, asphalt paving machine etc.
Compaction	Internal or external vibrators are used.	Rollers or compactors.
Strength	Relatively low	Relatively high
Surface roughness	Smooth	Rough and wavy due to roller compaction

Researchers have paid significant attention to RCC which is a type of zero slump product that is produced from the same materials with conventional concrete (Madhkhan et al., 2012). There are various applications of RCC in terms of cement amount contents. The suggested amount without any pozzolanic material utilization is 66 kg/m^3 (ACI 327, 2015). However the most commonly used cement amount in RCC mixtures within the range of 100 kg/m^3 and 200 kg/m^3 (Mardani-Aghabaglou and Ramyar, 2013). There are four typical methods for the design of RCC namely; corps of engineers' practice, high paste method, roller compacted dam method and maximum density method. These practices can be summarised as follows:

Corps of Engineers Method: This method is based on the W/C ratio and strength relationships. The amounts of water and maximum sizes of aggregates are dependent on the desired strength (Aghabaglou et al., 2019).

RCC Dam Method: It has 2 principles.

- The amount of cement must be as low as possible while having the desired strength. Furthermore, the mixture must contain flying ash in order to decrease hydration temperature.
- In order to prevent segregation and have more effective compaction sand/aggregate ratio must be higher than traditional mass concrete (Aghabaglou et al., 2019).

High Paste Method: This method requires to follow 3 steps;

- Under specific compaction energy, minimum gradation aggregate selection required;
- In order to obtain the required workability, the volume of the paste is determined by considering the gap volume between aggregates;
- In order to gain the necessary strength, water/cement ratio and pozzolanic content should be determined. Dry weight and water content are calculated.

Maximum Density Method: 90% of this mix by volume is formed by aggregate (both coarse and fine). Therefore, firstly aggregate is selected from the table (Aghabaglou et al., 2019).

Like the standard concrete, the strength of RCC depends on numerous factors namely; cement type, aggregate type, compaction, RCC strength and ambition conditions (Chhorn et al., 2018). These are all site conditions. As mentioned earlier, RCC roads can be opened to traffic earlier than its competitor asphalt. Strength development of RCC to 20 N/ mm^2 has vital role in opening the road as it is the minimum criteria used in the USA (Piggott, 1999). In warm weather RCC is capable of developing 20N/mm^2 strength within 2 days, in colder days this duration is determined to be 4 days (Toplicic-Curcic et al., 2015).

Development of RCC has led a significant shift in the construction projects primarily in dams, since the traditional practise of placing, compacting and consolidation of concrete are slow. By using RCC in earth and rock filled dams made the construction process quicker and consequently shortened the duration of construction. RCC used dam projects and be completed 1-2 years earlier than the ones in which conventional methods have been applied (Bagheri and Ghaemian, 2004).

Use of RCC has substantially increased in the last decades especially for pavement applications. It has a low construction cost and can be quickly constructed when compared to asphalt pavements. It is widely constructed in areas/ roads carrying heavy loads in low speed. On the other hand, in recent years' utilization of RCC in urban areas such as highways and streets has also increased (Harrington et al., 2010; LaHucik et al., 2017).

It has been proved that RCC has a competitive advantage over high performance asphalt pavements in terms of high compressive strength, durability, low maintenance cost, longer service life. Even though its share in the construction market is relatively low, it has gained significance in recent years. As a result of this growing interest in RCC applications, design methods have increased in recent years as well.

2. Characteristics of RCC

Overall, RCC is quite similar to conventional concrete in terms of ingredients and expected properties from it such as compressive & flexural strength, abrasion resistance etc. However, it has been proven that mechanical properties such as compressive, flexural strength, shear strength and toughness can be higher than traditional concrete (Madhkhan et al., 2015).

RCC differs from conventional concrete in terms of the required consistency which has a direct influence on the mix proportion requirement Khayat and Libre (2014). Compaction process has an essential role in the load carrying capacity of RCC as it creates friction between the aggregates or the particles (Hashemi et al., 2018). There are two main approaches to design RCC.

There are researches that observed compressive, flexural and tensile strength of RCC under the impact of different fibre or mixture material. These will be reviewed in the following sections. A brief summary of RCC production is shown in Fig. 1.

2.1. Workability and setting times

Workability and consistency of standard concrete are determined via the slump test. However, this test can't measure the workability of RCC. Ve-Be time is used to express workability for RCC concrete (ACI 327, 2015). It is suggested to have 20 up to 75 seconds of Ve-Be time in order to compactable concrete (Chhorn et al., 2018). Ve-Be time suggestions for RCC can be seen in Table 2.

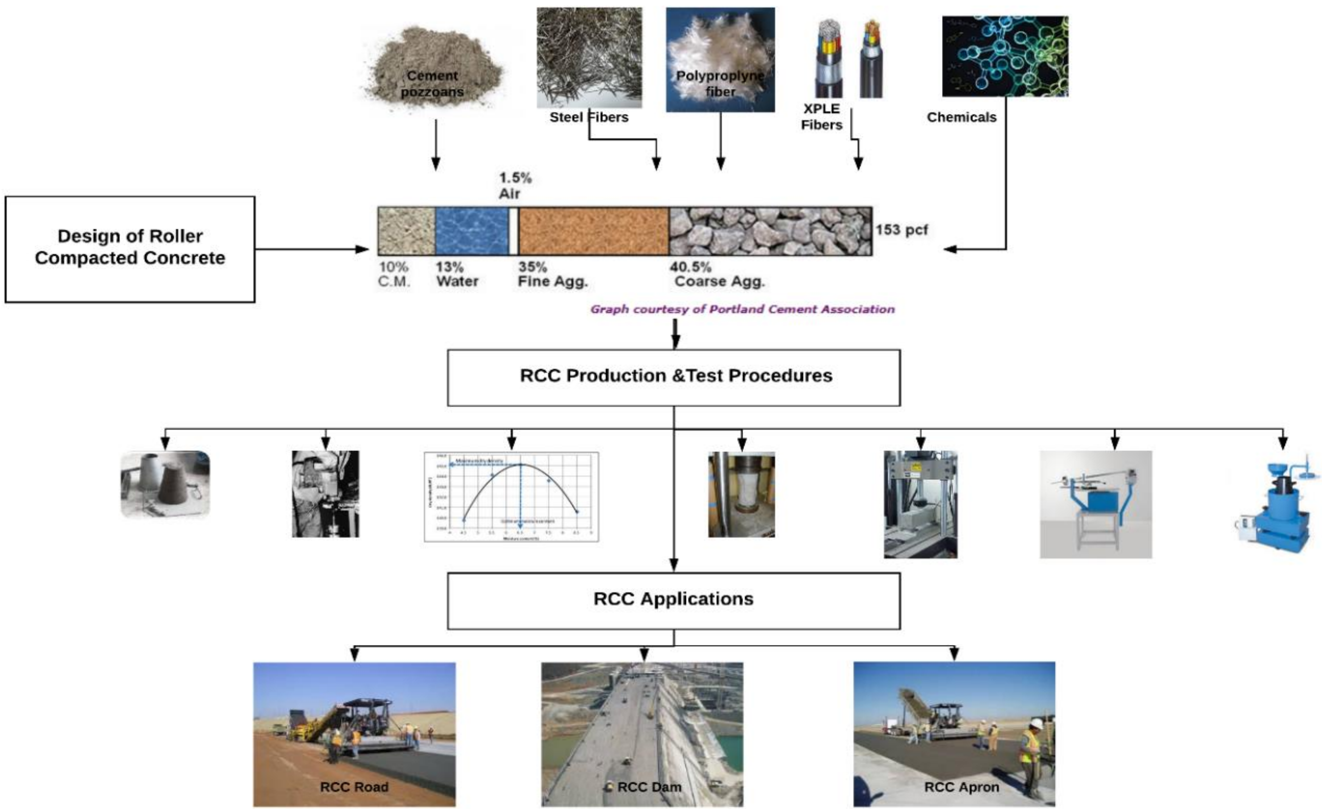

Fig. 1. RCC production chart.

Table 2. Recommended Ve-Be times and water content (Chhorn et al., 2018).

Modified Ve-Be times (s)	Optimum water content (%)
-	5 - 8
20 second for rollability, 30-40 is acceptable	4.5 – 6.5
30-40 seconds: appropriate	-
50-75 seconds: applicable	-

Addition of cross-linked polyethylene (XLPE) fibers have a positive effect on the workability of RCC and, Ve-Be times decrease with the increasing XLPE contents Shamsaei, Aghayan and Kazemi (2017). Natural pozzolan inclusion to RCC mixtures resulted in a decrease of Ve-Be time and workability property (Ghahari et al., 2017). Similarly with the addition of polypropylene fibre, workability decreases as reported in a study (Benouadah et al., 2017). This can be attributed to the high water absorption properties of natural pozzolans.

2.2. Evaluation of compressive strength

Compressive strength is a vital property for conventional concrete with or without fibre inclusion (Auta et al., 2015; Kiyanets, 2018). Like conventional concrete, RCC requires to conduct a compressive strength test. This test is performed with the combined conduction of vibrating table ASTM C1176-92, proctor ASTM C1557, coring tests ASTM C42. It is determined that 28 Days compressive strength of RCC cannot be less than 28 MPa (ACPA American Concrete Pavement Association, 2014).

Salt scaling that occurs due to saline solutions such as de-icer salt scaling is a common problem with RCC. A recent study by (Ghahari et al., 2017) investigated the effects of having pozzolan as cementitious material and air entraining agent to deal with salt scaling issue. It has been determined that the used pozzolan material had not increased the compressive strength. In fact, this had led approximately 9% decrease.

Furthermore, with the purpose of reducing the environmental effects of waste material, cross-linked polyethylene (XLPE) was utilized in RCC. XLPE is a widely used material for the insulation of electric wires and cables. According to the research by Shamsaei et al. (2017), utilisation of XLPE with as a replacement of aggregate decreased the unit weight of cement due to its low unit weight. However, it is also observed that the utilisation of XLPE decreased CS (Fig. 2d). Similarly when the amount of crumb rubber has increased, as a result CS decreased (Fig. 2c) (Adamu et al., 2018).

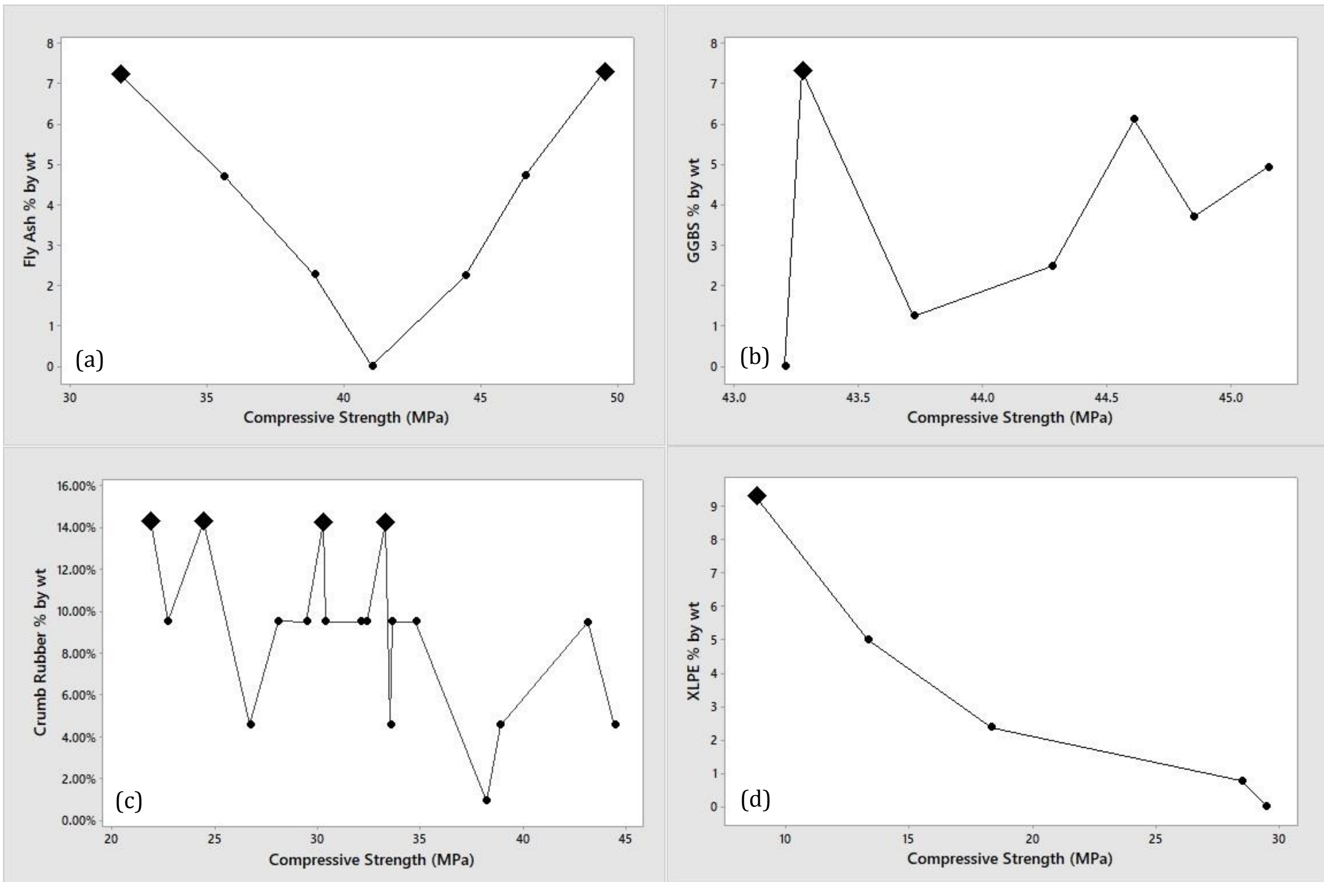

Fig. 2. Compressive strength of RCC with different content.

In a recent study, ground granulated blast furnace (GBBS) was replaced with cement. It was observed that compressive strength can be improved with the GBBS inclusion. In fact, GBBS addition can achieve compressive strengths as high as cement contributes (Rao et al., 2016a). Fly ash has a similar impact on RCC compared to the GBBS effects on RCC. When the amount removed from cement, added as fly ash the mixtures have almost the same compressive strength values. Based on these two experimental studies, it can be deduced that both fly ash and GBBS can be used as the cement replacement materials for RCC designs. Furthermore, when these additions are included in the concrete the mixtures show almost the same compressive strength results (Fig. 2b).

The effect of steel fibre addition in to RCC mixture was investigated as well. The test results in the recent study indicate that utilisation of steel fibre increased compressive strength approximately 20-30%. Similarly polyproline fibre made an incremental impact as well (Madhkhan et al., 2012). In a study efficiency of steel fibre in conventional concrete and RCC was investigated. It was observed that steel efficiency in RCC is significantly higher than in conventional concrete (Karadelis and Lin, 2015). Polypropylene fibre has also similar increasing effect on RCC (Benouadah et al., 2017).

However, the other research conducted in Thailand indicate that addition of steel fibre to RCC results in decrease of compressive strength slightly (Sukontasukkul et al., 2019).

Summary of literature review can be seen in Table 3.

It can be concluded that, having different fibres or components have both incremental and decremental effect on compressive strength of RCC.

Table 3. RCC literature review summary.

References	Compressive Strength (MPa)	Flexural Strength (MPa)	Material utilized	Observation
Chhorn et al. (2018)	24.30	-	Fly Ash	Compressive strength decreased.
Shamsaei et al. (2017)	28.49	5.51	Cross linked polyethylene (XLPE) fibre	With 5% XLPE use by weight, the CS decreased by 3.42%.
LaHucik et al. (2017)	56.60	1.45	Macro fibers with several geometries.	If properly constructed, fibre added RCC has similar or better performance than Portland Cement Concrete in terms of fatigue resistance.
Ghahari et al. (2017)	34.30	-	Natural pozzolan	20% by weight of cement is replaced with trass natural pozzolan. At the early ages, samples show 35% lower compressive strengths, this develops and at the late of 90 days the difference gets to 14%.
Rao et al. (2016a)	45.15	7.90	Ground Granulated Blast Furnace Slag (GGBS)	Cement was replaced with GGBS. Compressive strength increased by 4.51%.
Mardani-Aghabaglou and Ramyar (2013)	49.50	5.16	High volume fly ash	Fly ash contributes compressive strength of the concrete mixture.
Adamu et al. (2018)	44.46		High volume fly ash and crumb rubber	According to the test and optimisation results best performance can be obtained by replacing; 10% of fine aggregate with crumb rubber, 53.72% of cement with fly ash.

2.3. Evaluation of flexural & tensile strength

Flexural strength of RCC is important for its service quality as it is important for conventional concrete. In the recent study impact of cross-linked polyethylene (XLPE) which is a waste material, in RCC was investigated. XLPE was used to replace coarse aggregate with various amounts 5%, 15% and 30%. With 5% of XLPE, the flexural strength of RCC is determined to be lower than the sample 0. The trend with the increase of XLPE for flexural strength is downward as shown in Fig. 3d. However, still these specimens meet the minimum requirement of RCC guide (Shamsaei et al., 2017).

In other experimental research cement was replaced with Ground Granulated Blast Furnace Slag (GGBF) with different volumes (10%, 20%, 30%, 40%, 50% and 60%). It was observed that GGBF has an incremental effect on RCC flexural strength (Fig. 3c). When cement is reduced by increasing GGBS, flexural strength goes up. It has a similar effect on split tensile as well. With the increased amount of GGBF split tensile shows an increasing trend (Rao et al., 2016a). The impact of utilization of fly ash in RCC showed the same results as well (Fig. 3a) (Mardani-Aghabaglou and Ramyar, 2013).

2.4. Elastic modulus

Modulus of elasticity of RCC is not generally measured from the samples on site. The factors that determine the modulus of elasticity are aggregate type, paste volume age and strength (Omran et al., 2017). Modulus of elasticity of RCC is generally similar or higher than the modulus of elasticity of normal concrete with the same amount of cement (Berry and Tayabji, 2001). Fibre addition can increase (Nanni and Johari, 1989), or decrease (Muscalu et al., 2013) Elastic Modulus of RCC. Graphical illustration is shown in Fig. 4.

In the recent study, Elastic Modulus of RCC was investigated in fibre added RCC samples (LaHucik et al., 2017). The sample with fibre made steel shows the greatest Elastic Modulus. It can be seen in the table above. However, unlike the other studies, it was, showed in the study that the inclusion of fibre had no statistical impact on the modulus of elasticity of RCC (LaHucik et al., 2017).

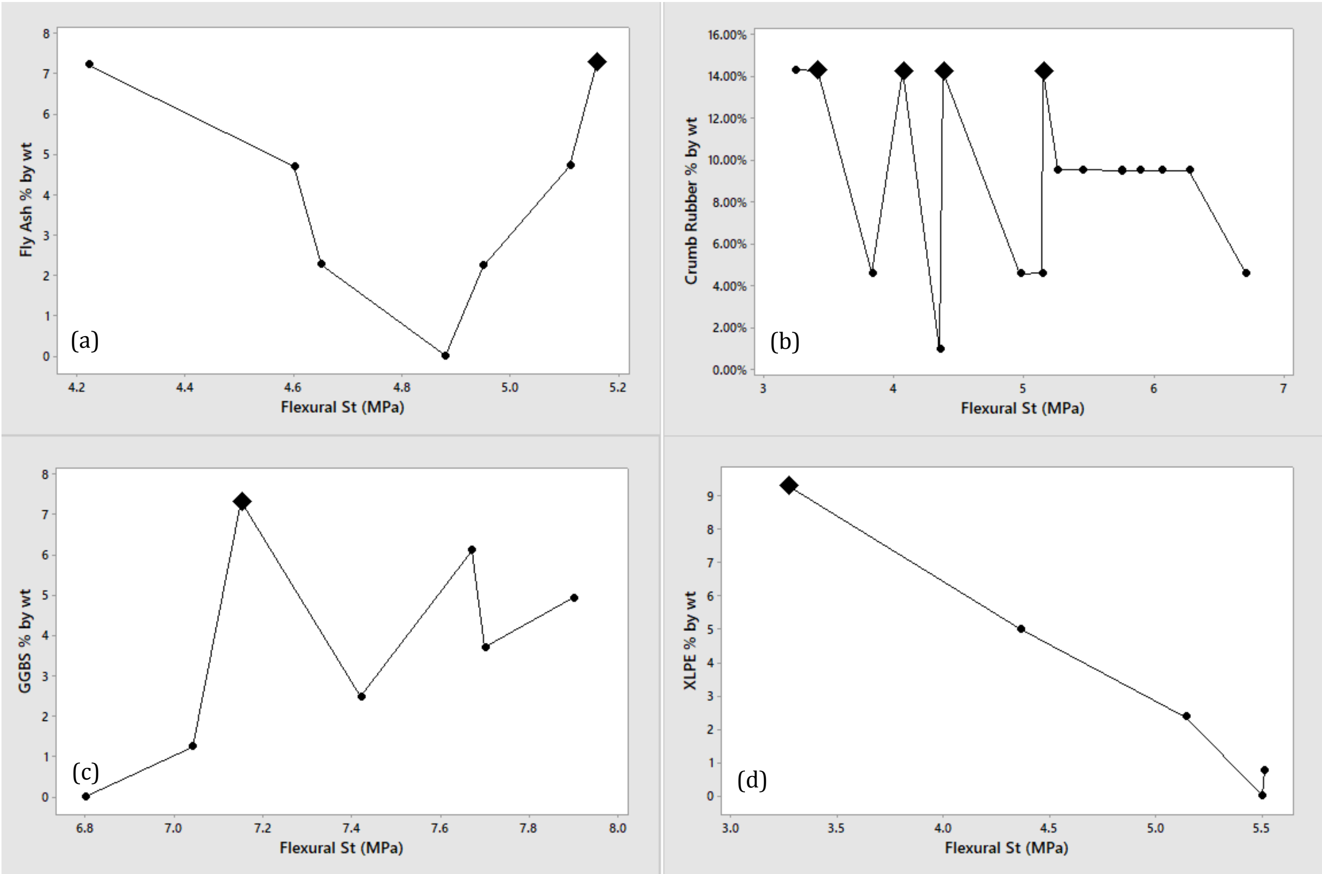

Fig. 3. Flexural strength of RCC with different content.

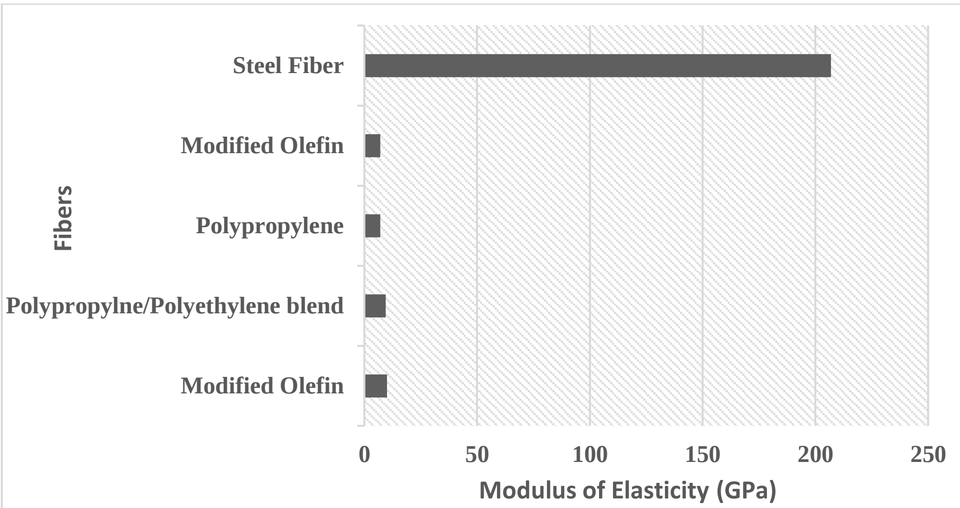

Fig. 4. Elastic Modulus of RCC with different fibers.

2.5. Durability and microstructure properties of RCC

Due to sliding and scraping action of wheels, vehicular movements lead abrasion on the pavements (Rao et al., 2016b). Therefore, abrasion resistance of RCC especially in transportation projects is vital. Abrasion tests are performed according to ASTM C944 in order to determine surface resistance of RCC. RCC is placed to the construction site by using finisher and compactor. Owing to its installation method RCC is capable of developing excellent durability (Benouadah et al., 2017).

There are a few criteria that measure the abrasion resistance of concrete namely; viz., aggregate proportion, type of aggregate (both fine and coarse), strength, mix ratio, fibre content, curing methods and method of the surface to finish (Rao et al., 2016a). According to test results even though RCC sample had low abrasion resistance at an early age, later-on it significantly increases. Furthermore, fly ash increase abrasion resistance of 30% (Won et al., 2009).In the other study when the cement has been replaced with high volume fly ash, abrasion resistance decreases. It was also determined that the addition of crumb rubber as the replacement of aggregate has the same effect on the concrete mix (Adamu et al., 2018).

In the recent study, the effect of cationic asphalt emulsion as an admixture to RCC was investigated. The design was completed according to density method ASTM D1557. The transport properties of RCC can be developed by adding asphalt. Furthermore asphalt addition reduces the amount of capillary pores, as it is shown in Fig. 5 (Dareyni et al., 2018). It can be easily detected that the capillary pores are filled by asphalt.

Effects of electric arc furnace steel slag incorporation on the mechanical and fracture properties of RCC was investigated. Splitting tensile and compressive strength were determined to be higher than the control mixture (Rooholamini et al., 2019). Microstructure of electric arc furnace steel slag and River used RCC can be seen in Fig. 6(a-d). River filler has denser structure while EAF slag shows rare structure in the comparison. EAF slag is finer and smoother than river filler. It can be deduced that EAF filler has more specific area.

Frost resistance of RCC is significant property for RCC considering the area they are used such as roads and dams. In the recent study effects of rubber and steel fibres on frost resistance of RCC was investigated. The test results indicate that either steel fibre or rubber fibre does not improve frost resistance of RCC (Zhang et al., 2018). In Fig. 7, microstructure of steel fiber added RCC can be seen. It is observed that bonding surface of mortar without freeze-thaw cycle is clean. An obvious interface between the steel fibre and mortar is also seen in the SEM analysis photo (Fig. 7).

Glass powder (GP) was used as replacement of cement in RCC and effects have been reviewed. Adding glass powder contributes mechanical properties (compressive and flexural strength) of RCC. Increase has been observed especially at later age of 91 and beyond. This could be useful improvement against the weather conditions (Omran et al., 2017). Glass has impermeable property, which leads GP included RCC to have lower permeability. In dry condition GP is weakly hydrated (Fig. 8).

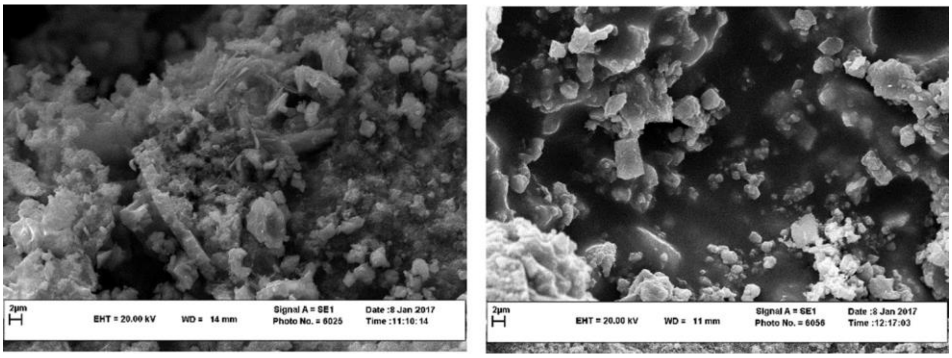

Fig. 5. Micro structure of asphalt added RCC (Dareyni et al., 2018).

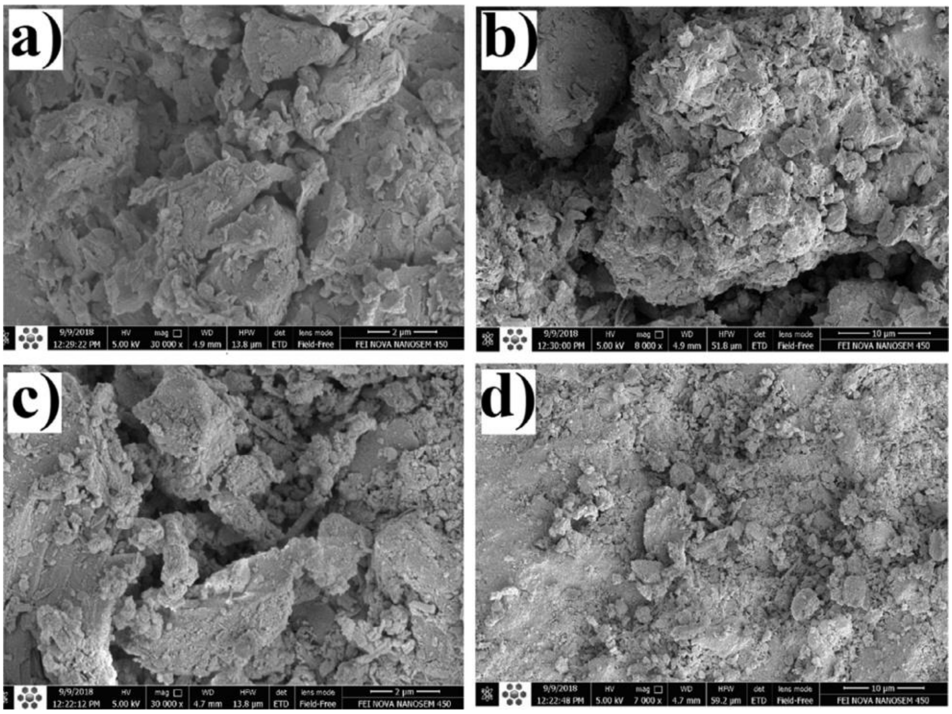

Fig. 6. Micro structure of steel slag added RCC (Rooholamini et al., 2019).

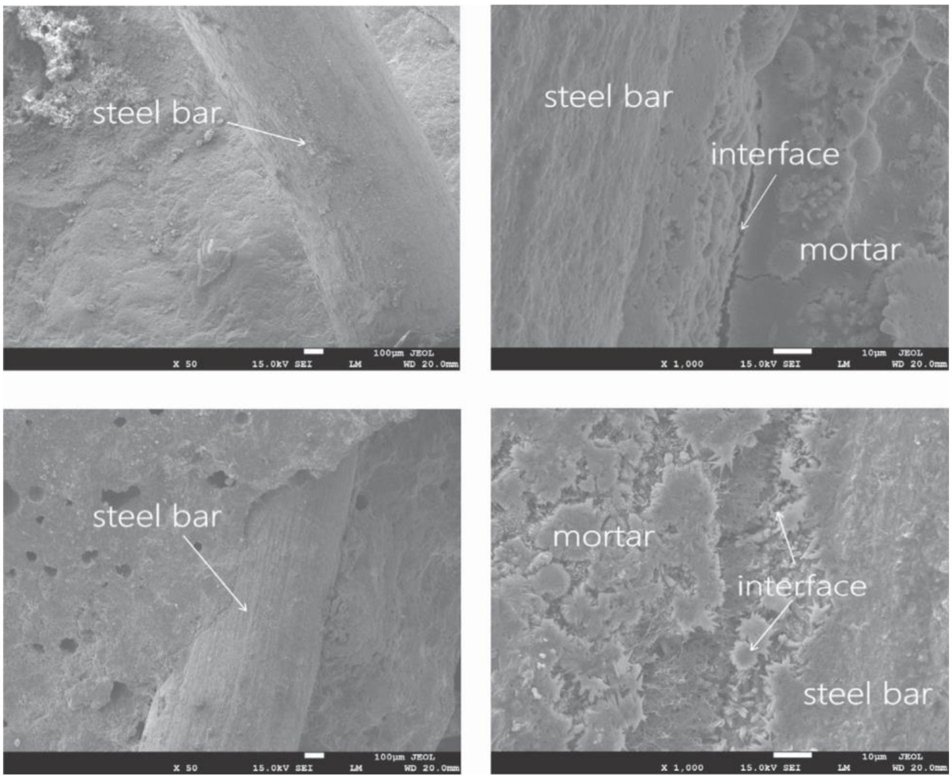

Fig. 7. Micro structure of fibre added RCC (Zhang et al., 2018).

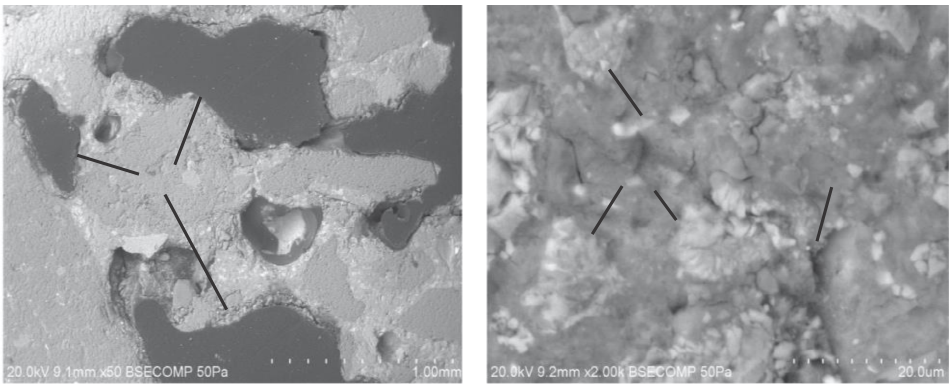

Fig. 8. Micro structure of glass powder added RCC (Omran et al., 2017).

3. Cost Comparison

RCC is worldwide regarded as low cost material which is derived from its ability to be produced and placed in to construction area owing to its characteristics (Won et al., 2009).. The ratio between mechanical properties of RCC and overall cost of RCC construction, operation and maintenance stages is reasonably good (Bílý et al., 2015). The report was issued in U.S.A indicates that %30 cost saving is possible by using RCC in comparison with asphalt or conventional concrete (Pavement, 1990). The other report on the hand, reviews the practices in the Europe and states that with RCC applications there is cost saving up to %12 (Neocleous et al., 2011). A real case study which was priced in USA indicates that cost of RCC per square yard is 12.35$ while asphalt price is 19.62$ (Damrongwiriyanupap et al., 2012). Other report states that as an alternative to asphalt pavement RCC costs higher (Report, 2015). It is obvious that it is not possible draw a conclusion and claim that RCC or Asphalt cost is lower than the other. In fact, it depends on multiple things such as; the country, concrete production facilities, availability of the raw materials, financial strength of the country (currency exchange rates). Hence to be able to make a decision, it requires deeper investigation and it has to be unique research for the proposed construction work.

Fiber addition is limited application throughout the world due to high cost of fibers. However this extra cost can be compensated by the rapid construction of RCC. Recent study indicates that steel fiber RCC leads to both cost saving and construction time by at least 10% and energy consumption by 40% (Neocleous et al., 2011).

Table 4. Cost Comparison from a real construction works bid (Damrongwiriyanupap et al., 2012).

Cost	Roller Compacted Concrete	Asphalt State-Constructed	Asphalt In-Place Bid
Total	$29,111	$34,486	$46,961
Cost per square yard	$12.35	$14.63	$19.62

4. Environmental Benefits of RCC and Its Asphalt Comparison

Sustainability has become a widespread and common concern in all countries since the late 80's when it was first mentioned. Term of sustainability can be defined as the utilisation of the natural resources by considering the future generations and ensuring that they will have enough resources. Therefore, the amount of resource consumption should be reasonable (Yılmaz and Bakış, 2015). Due to reducing natural resources environmental concerns and sensitivity of non-governmental organisations', the focus of engineering is now directed towards sustainability. On the contrary to common perception, advancements in cement production have significantly decreased the CO_2 emissions in recent years (Sabnis, 2016). Furthermore, RCC is capable of being a sustainable alternative by reducing the amount of utilised material, saving cost and excavation (Abdo, 2010).

As it can be seen in Fig. 9, RCC can be a valuable solution to the engineering problems. Even after the value engineering process, RCC is still capable of optimizing the value engineered solution by reducing the designed HMA wear and HMA base. Furthermore, with the RCC the depth to be excavated less, this gives side benefits as well. With few works at the site, construction works, less workmanship etc.; easy to open for traffic.

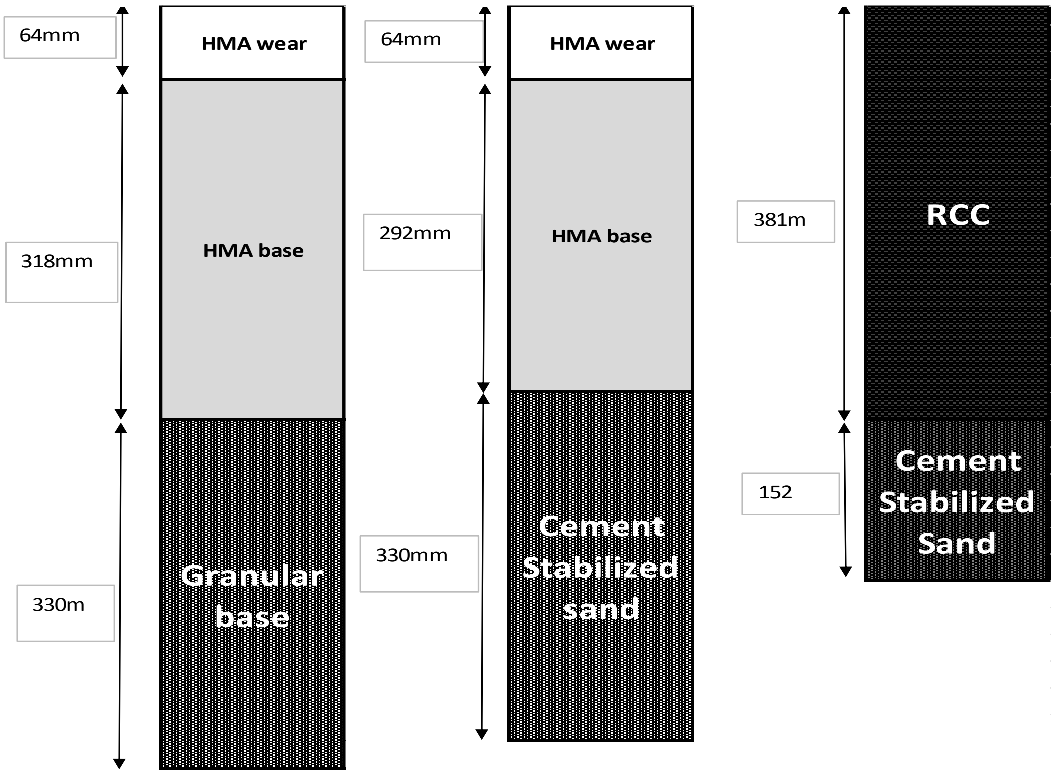

Fig. 9. Sustainable RCC solution considered in a real project (Abdo, 2010).

In this respect, benefits of RCC have been seen by many countries, and the number of RCC dams have increased recently (Figs. 10 and 11). USA has been using RCC in military, public and private/industrial projects. The most common area in which RCC used is dams.

RCC use can be an effective way to reduce the utilisation of materials. Less material used more sustainability is achieved. RCC applications can be successful in less energy consumption and results in 40% less energy use (Neocleous et al., 2011). Furthermore, with the help of technology in cement production, CO_2 emissions can be reduced which consequently leads less mission. Likewise, with the help of fibre or binding alternatives the amount of cement in the concrete can also be reduced.

The other increasing area of utilisation of RCC is in pavements (Sabnis, 2016). Yet, the overall RCC share in the total paved road length in the United States, which is 45.771 km out of 482,924 km. In other words even one of the larger RCC road builder countries has only 9.5% share in its own country (Reza and Boriboonsomsin, 2015).

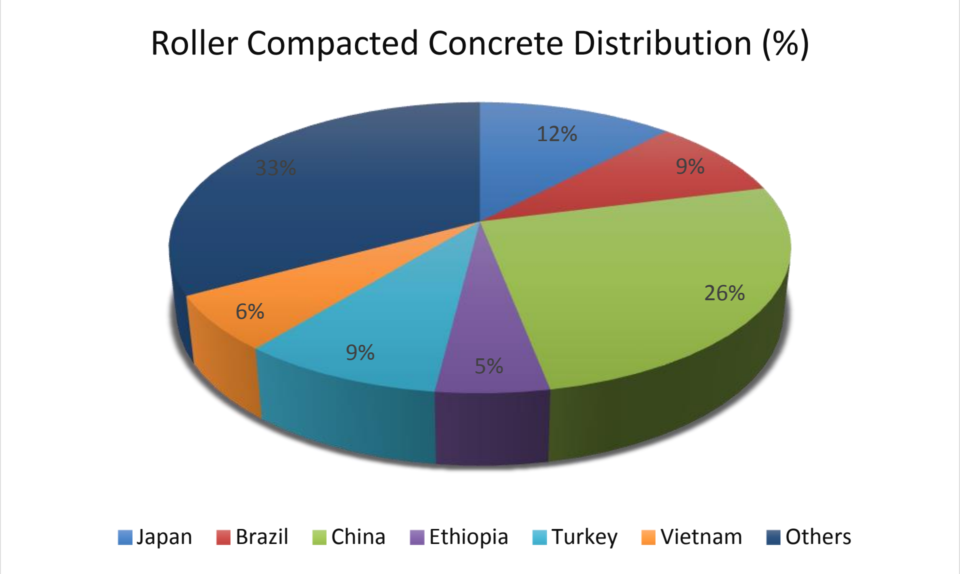

Fig. 10. Country basis RCC dam (%).

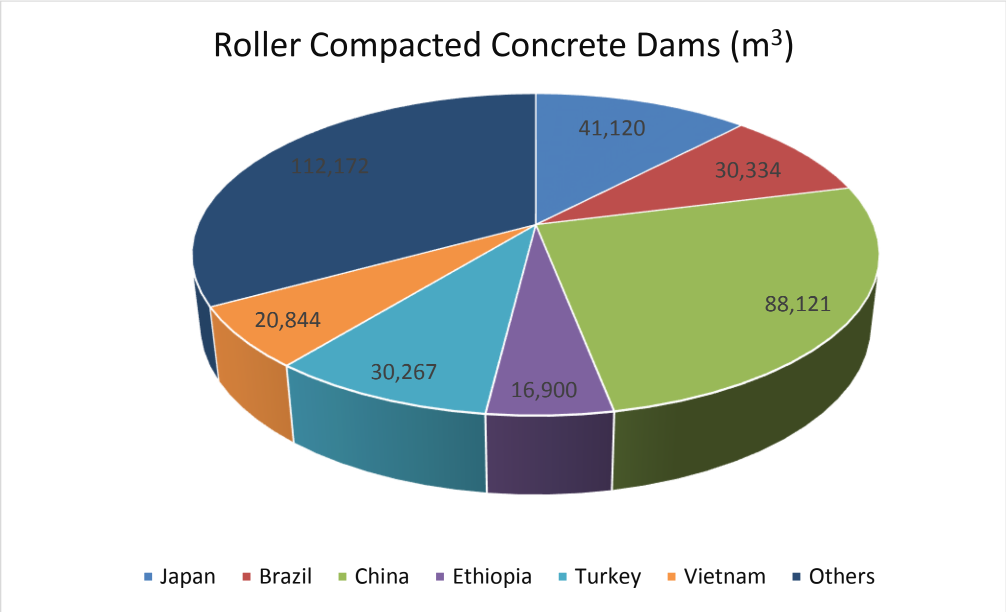

Fig. 11. Country basis RCC dam (m^3).

5. Conclusions

Workability is a significant criterion for RCC. It is mainly dependent on ; aggregate gradation, water content (Chhorn et al., 2018), fibre addition (Ghahari et al., 2017; Adamu et al., 2018) and pozzolan content (Shamsaei et al., 2017). Therefore, it requires significant attention in the mix and production phases.

In terms of having compressive strength RCC can show satisfactory performance with or without fibre addition. Steel fibre is the most preferred fibre addition that improves its CS and can be a strength improver. In this respect, RCC is alike conventional concrete. Pozzolan can be an excellent alternative material as replacement of cement which results in a decrease in cement use.

Fiber inclusion is a practise that done with the purpose of increasing properties of RCC. However, in terms of cost, volume of material constructed at site, fiber added RCC is preferred to have the same or less thickness than with no fiber content RCC. Recent study indicates that fiber addition does not increase the thickness of pavement. In fact the thickness of normal RCC without fibre is determined to be 45.72 cm (18 inch), while fiber added RCC thickness is 35.56 cm (14 inch) (Nanni, 2002). Therefore, fiber addition has positive impact on the layer thickness.

The value and advantages of RCC have been recognized by many countries including U.S.A, Japan, and this is increasing. It is widely used in dam projects owing to its mechanical properties, less cement used with the help of pozzolan, less cost and not require tensile strength

(Berga and Buil, 2003). In pavements the reasons for selection are quite similar. Due to less cost of RCC, easiness to open to the traffic, high compressive strength, and longer service life are the main reasons for RCC to be preferred. RCC applications both in pavement and dam projects look promising. According to the cost comparison of 1m^3, it has a significant advantage over asphalt. However, in order to get a more in-depth view, the total cost of asphalt production and RCC production should be investigated in deep.

RCC application is environment friendly and sustainable application. Cement can be replaced with pozzolan, required strength can be developed by fibre addition. This results in less cement used and consequently less cement production. However. A deeper investigation should be carried out in order to make a fair comparison of CO_2 emission for both RCC and asphalt production phases.

This study investigated the RCC and its use, advantages and disadvantages. It is obvious that RCC has its own pros and cons. However, it can be appropriate applications especially in City Street and urban areas.

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