International Journal of Advance Civil Engineering and Technology
Volume 2, Issue 2, July-December, 2017

# *Application of Artificial Neural Network for Ultimate Strength of Sustainable Recycled Aggregate Concrete*

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## *Abstract*

*Earth is facing major environment related problems today such as Global warming and loss of bio-diversity. This brings in the need for Sustainable development, which meets the needs of the present without compromising the ability of future generations to meet theirs. Use of recycled materials in construction, such as recycled aggregates, fly ash, silica fume etc. leads us to less energy consumption in terms of production of cement, transportation etc., less quarrying and thus protection of bio diversity at both quarrying site and dumping sites. But properties of recycled material such as recycled aggregate are substantially different from that of natural aggregates hence prediction of performance of RAC becomes difficult. Here, an attempt is made to predict performance of RAC concrete using modern soft computing tool, i.e. Artificial Neural Network. 136 sets of experimental data from various literature sources were used to train and test the ANN model. The developed ANN model used 14 input parameters and compressive strength at 28 days as output parameter. The results showed that ANN has good potential to be used as a tool to predict strength of sustainable RAC concrete prepared with varying types, sources and ages of recycled aggregate and using industrial wastes.*

***Keywords:*** *Sustainable development, recycled aggregates, Artificial neural network*

## INTRODUCTION

This Concrete is the most popular construction material across the world. Aggregates are the major component of concrete. For last few years the cost of aggregates is increasing rapidly. Quality of aggregates is also depleting year by year. Popularity of concrete also causes big damage to environment as billion tons of natural aggregates are being quarried from rock each year. Large scale production of cement requires huge amount of energy and large amount of natural materials like limestone, clay etc. Also, large quantities of CO2 are released into the atmosphere in the process. There is a need to economize the use of cement and aggregates from sustainable construction point of view. This study points to some efforts to economize the use of aggregates and cement.

Large quantities of wastes from construction and demolition works are produced every year and the production is increasing year by year. Large quantities of waste materials and by-products like fly ash, GGBS etc. are generated from industrial processes. As per report of Hindu online of March 2007, India generates 23.75 million tons demolition waste annually. As per report of Central Pollution Control Board (CPCB) Delhi, in India, 48million tons solid waste is produced out of which 14.5 million tons waste is produced from the construction waste sector, out of which only 3% waste is used for embankment.

We are wasting majority of these materials by dumping as landfills which causes shortage of dumping places in large cities. Use of such waste materials in concrete can considerably reduce the problem of shortage of dumping places and simultaneously it helps in the preservation of natural aggregate resources and its ecosystem. So, if C and D waste is used instead of natural aggregates and industrial wastes such as fly ash, GGBS, rice husk ash etc. are used as partial replacement of cement, without affecting the mechanical properties of concrete, we can achieve economic and environmental benefit.

## RECYCLED AGGREGATES

The reuse of hardened concrete as aggregate is a proven technology - it can be crushed and reused as a partial replacement for natural aggregate in new concrete construction. The hardened concrete can be sourced from the demolition of concrete structures at the end of their life. Recycling or recovering concrete materials has two main advantages - it conserves the use of natural aggregate and the associated environmental costs of exploit1ation and transportation, and it preserves the use of landfill for materials which cannot be recycled. Recycled aggregate is traditionally used as landfill. It has also found many applications in recent years. Recycled aggregate has been used as base layer in pavements, subgrade stabilization, in concrete kerbs, embankment fill, backfill material, in paving blocks etc. Though it has been used for above mentioned purposes, its usage is not very popular. This is because of the fact that it has different properties from that of natural aggregates.

Recycled aggregates are found to be more angular in shape, have lower bulk and SSD specific densities, higher water absorption, inferior strength, presence of contaminants (e.g. ceramic) and lower resistance to mechanical and chemical actions. Because of these differences, the properties of concrete made with RA are often inferior to those concrete made with only NA due principally to the highwater absorption and low density of RA. Normally, in using recycled aggregates for making new concrete, only the coarse aggregates are used. This is due to recycled fine aggregates normally have very high water absorption values rendering them not suitable for making new concrete [19] as it would lead to excessive drying shrinkage. So only the use of recycled coarse aggregate in new concrete is considered here.

The need of the hour is to bring recycled aggregates into mainstream construction. Several market constraints and technical challenges exist when developing markets for secondary products like recycled aggregates. Notable among these barriers is consumer uncertainty about the quality and consistency of products. Recycled aggregate also faces these challenges as properties of aggregate depend on source of old concrete, age of old concrete, crushing technology used etc. So, we need a kind of intelligent analysis tool to predict the performance of concrete in which recycled aggregates from various sources and properties is used.

## ARTIFICIAL NEURAL NETWORK

The properties of concrete, including its compressive strength are a highly nonlinear function of its constituents. Various studies have shown that concrete's strength not only depend on water-to-cement ratio, but is also related to the other additive constituents (Oluokun, 1994). The lack of standard empirical relationships to judge the compressive strength of concrete based on its constituents has created the interest of the researchers towards soft computing tools. (Chaturvedi, 2008) has defined Soft Computing as an emerging collection of methodologies which aim to exploit tolerance for imprecision, uncertainty and partial truth to achieve robustness, tractability and total low cost. Soft computing harnesses statistical, probabilistic and optimization tools for learning, predicting and classifying new patterns based on the past data. Artificial Neural Networks (ANNs) touted as the next generation of computing forms a sub-setof Soft Computing Tools. Artificial neural networks are massively parallel adaptive networks of simple nonlinear computing elements called neurons, which are intended to abstract and model some of the functionality of human nervous system in an attempt to partially capture some of its computational strengths (Kumar, 2013). As compared to conventional digital computing techniques, and procedural and symbolic processing, neural networks are advantageous because they can learn from example and generalize solutions to new renderings of a problem, can adapt to fine changes in the nature of a problem, are tolerant to errors in the input data, can process information rapidly, and are readily transportable between computing systems (Flood and Kartam, 1994).

The unconventional method of deriving information through learning has created immense interest in the field of neural networks. The capability of artificial neural networks to act as universal function approximator has been traditionally used to model problems in which therelationship between the dependent and independent variable is not clearly understood (Aggarwal and Aggarwal, 2011). Due to the black-box nature of neural networks, there is no need to assume any functional relationship among the various variables. ANNs automatically constructs the relationships and adapts itself based on the data used for training.

ANNs modelling ability to derive meaning from unknown and non-linear interrelationships among variables have been harnessed to aid the prediction of behavior of engineering and natural systems. Concrete‟s compressive strength is one such problem that is unstructured in nature involving highly non-linear relationships among its constituents and compressive strength.

Therefore an attempt is made here to develop a tool to provide a more accurate estimation for the compressive strength of sustainable recycled aggregate concrete. The ultimate goal, if not totally eliminating the need for the experimental determination of the Compressive strength or other concrete properties in the future, is to significantly reduce such a need, which will save time and money for the industry.

## EXPERIMENTAL DESIGN

A total of 14 input parameters were chosen to design the model to give one output value which is compressive strength of concrete at 28 days.

### *4.1. Selection of input parameters.*

The factors which affect the most in strength gain of concrete are to be considered as input parameters.

### *4.1.1. Concrete constituents*

Quantity of cement, water, sand, natural aggregates and recycled aggregate are the most important factors affecting strength of concrete, hence these were considered.

### *4.1.2. Nature of Aggregates*

The fineness modulus of sand, overlooked in many studies, is also an important factor, can directly influence the workability, strength, impermeability and other properties.

In addition, the quality of coarse aggregates, such as maximum particle size, SSD specific gravity and water absorption values, is another factor that affects the RAC strength greatly [25]. As the sources and crushing processes from which the RA was obtained in this paper were quite different, the properties of the coarse aggregates used varied greatly.

As the strength of aggregate is much higher than the strength of cement paste, so for low to medium strength concrete considered in this study, the strength of concrete is only slightly affected by the strength of the aggregates. So in this paper, the strength index of the aggregates is not considered. Also, most of the published work did not have information on strength data (crushing value or 10-percent fine value).of the aggregates used in the concrete mixes.

The impurities in RA can significantly affect the performance of RAC. Generally speaking, RA, produced from old concrete test cubes or cylinders, are 100% concrete, while RA obtained from old buildings or old pavements contain small amounts of soft soils, natural stones, clay bricks, and other impurities like paper, wood, glass, tiles and metals [40]. As the contents of impurities in RA generated from different sources are different, they should be considered when preparing RAC.

Table 1 shows the list of input parameter used in this study.

### *4.2. Selection of output parameter*

The 28 day compressive strength of concrete was the output parameter considered in this study.

### *4.3. Data collection*

A total of 136 sets of experimental data from different literature sources were collected to train and check the reliability of the strength model [36-46].

The available data was randomly divided into three parts: the first part with 75% of data was used in the training set, the second part with 12.5% of data, were used in the validation set, while the third part was used in the testing set, to test the accuracy of the prediction.

***Table 1: List of parameters***

| Parameter | Min. | Max |
|---|---|---|
| Cement (kg/m3) | 220 | 450 |
| Mineral Admixture(kg/m3) | 0 | 102.5 |
| Water(kg/m3) | 120 | 271 |
| Sand(kg/m3) | 540 | 1020 |
| N.A. (kg/m3) | 0 | 1186.18 |
| R.A. (kg/m3) | 0 | 1070.9 |
| W/C | 0.3 | 0.76 |

| | | |
|---|---|---|
| F.M. | 2.11 | 3.88 |
| Max. size of CA(mm) | 12.5 | 25 |
| Water Absorption (%) | 2.24 | 10.6 |
| SSD Spe. Gravity | 2.27 | 2.76 |
| Rv (%) | 0 | 100 |
| Chemical Admixture (%) | 0 | 3 |
| Impurity content (%) | 0 | 5 |
| Compressive strength (MPa) | 17 | 85 |

### *4.4. Construction of the ANN model*

A feed forward back-propagation network was adopted in this research. It has 14 neurons (variables) in the input layer and one unit in the output layer. The values of network parameters considered in this approach are as follows: number of hidden layers = 0, 1, and 2; number of hidden neurons = 2-50; learning rate = 0.01,0.1, 0.3, 0.5, 0.7, 0.9, 1.0, and 2.0; momentum factor = 0.0, 0.3, 0.5, 0.7, 0.9 and 1; and learning cycles = 500, 1000, 5000, 10,000, 20,000 and 50,000 (each cycle covers the entire database available for training).

Solver functions = lbfgs (Quasi- newton), Levenberg-Marquardt and Conjugate Gradient Decent (CGD)

Activation functions = hyperbolic tangent(tanh), logistic, linear.

Based on the error of integral testing set after a series of trials, the best network architecture and parameters that maximize the R2 values of testing data are as follows.

Number of input layer units = 14
Number of hidden layers = 1
Number of hidden layer units = 30
Number of output layer units = 1
Momentum rate = 0.1
Learning cycle = 1000
Solver function = Quasi-Newton
Activation function = hyperbolic tangent.

## V. RESULTS AND DISCUSSIONS

The performance of the network is judged based on R2 (Coefficient of determination), MAE (mean absolute error) and Correlation coefficient values. Table 2 shows the results for the best network model.

***Table 2: Performance of network***

| | Test set | Training set | All sets |
|---|---|---|---|
| R^2 | 0.95 | 0.94 | 0.94 |
| MAE | 2.19 | 2.36 | 2.47 |
| Correlation | 0.98 | 0.97 | 0.97 |

It can be seen that coefficient of determination value was 0.95 for test set and 0.94 for training set and also for all sets considered together. MAE value was 2.19 for test set, 2.36 for training set and 2.94 for all sets. Correlation value of 0.98 was obtained for testing set. It has been demonstrated that the constructed ANN model was able to provide prediction of the 28-day compressive strength of RAC close to that of the experimentally determined values.

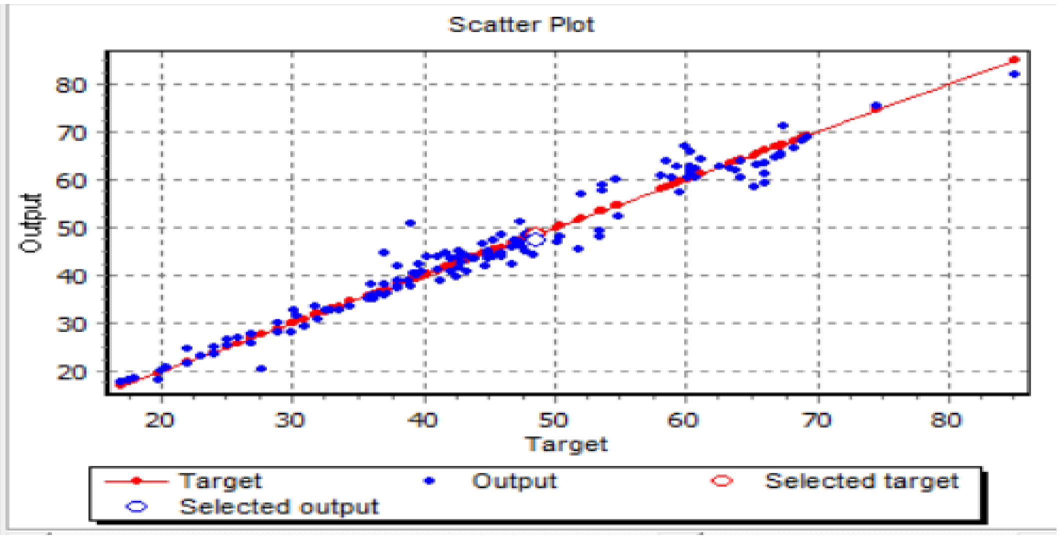

***Fig. 1 a Training set***

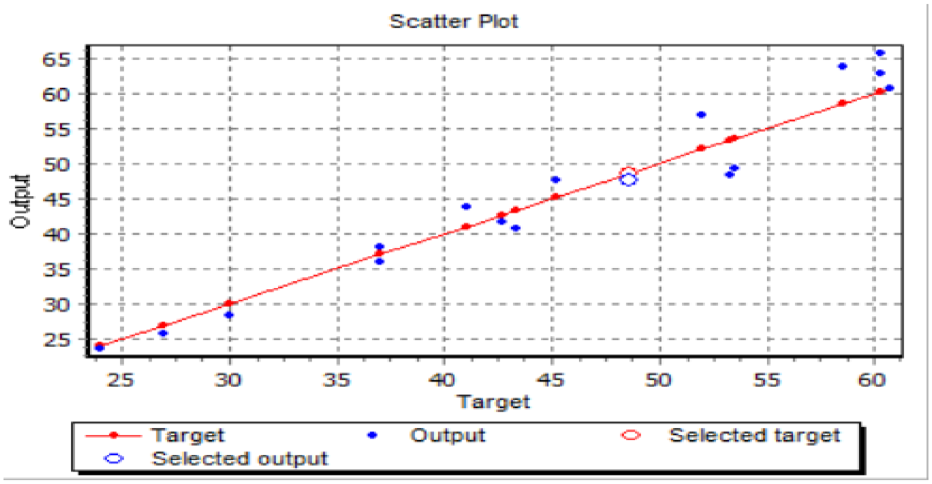

*Fig. 1b Testing set*

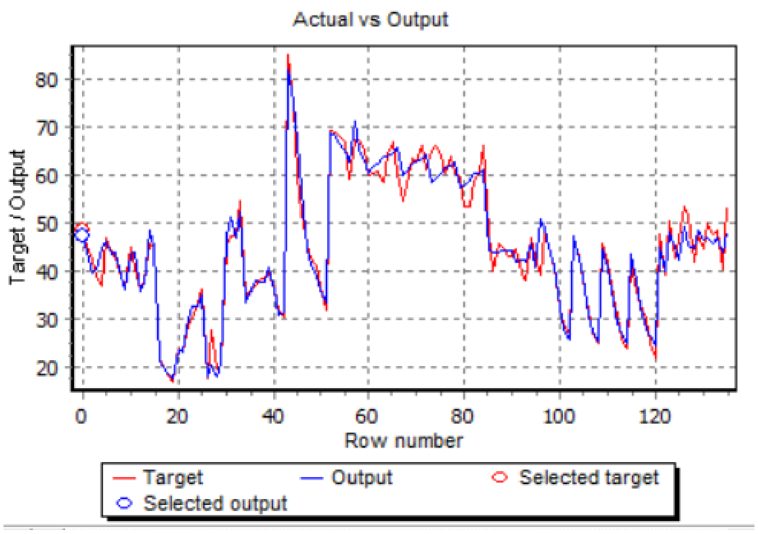

*Fig. 2 Validation of ANN model using 28 days compressive strength data from literature*

The performance of ANN, when compared with the actual values can be seen in Figs. 1a and 1b , from which it can be concluded that the proposed neural network could learn the relationship between the different input parameters and the output parameter. Also, it was able to model the compressive strength of concrete made with RA. A comparison of actual values and the predicted ones is listed in Table 3.

*Table 3: Comparison of actual and predicted values*

| Sr. no. | Actual value | Predicted value | Absolute error | Absolute Relative error |
|---|---|---|---|---|
| 1 | 43.8 | 43.45 | 0.35 | 0.79% |
| 2 | 38.9 | 41.2 | 2.3 | 5.91% |
| 3 | 20 | 22.27 | 2.27 | 11.35% |
| 4 | 36.16 | 33.94 | 2.22 | 6.13% |
| 5 | 35.8 | 32.78 | 3.02 | 8.43% |
| 6 | 32.04 | 32.06 | 0.02 | 0.06% |
| 7 | 68.82 | 69.85 | 1.03 | 1.49% |
| 8 | 60.72 | 60.91 | 0.19 | 0.31% |
| 9 | 64.2 | 61.34 | 2.86 | 4.45% |
| 10 | 65.12 | 59.34 | 5.78 | 8.87% |
| 11 | 60.72 | 58.58 | 2.14 | 3.52% |
| 12 | 44.9 | 43.01 | 1.89 | 4.20% |
| 13 | 44 | 43.08 | 0.92 | 2.09% |
| 14 | 43 | 39.36 | 3.64 | 8.46% |
| 15 | 36 | 39.84 | 3.84 | 10.66% |
| 16 | 50.41 | 46.14 | 4.27 | 8.47% |
| 17 | 53.34 | 53.88 | 0.54 | 1.01% |

Based on Table 3, the following can be observed:

The maximum and minimum absolute errors in the testing sets were 5.78 MPa and 0.02 MPa, respectively, with the individual values mainly in the range of 0–3 MPa; while the largest and smallest relative errors were 11.35% and 0.06%, respectively, and the average relative error of the total 17 sets of test data was about 5.07%, which can be considered as good and acceptable.

The constructed ANN model exhibited good prediction performance; it was able to fit most of the compressive strength values close to the target strength.

Some of the test data, did not fit very well, and this might be due to several reasons including:

(1) Erroneous experimental data itself, especially after converting the original test values to the 150 mm equivalent cube strength.

(2) Cement type was not considered as an input parameter. As the details of the cement used in some of the literatures had not been reported.

(3) Different characteristics of RA, such as the processing methods used to produce the RA, sources of RA and the strength index of the RA, etc.

In summary, the test results showed that the constructed ANN model was able to predict the compressive strength values of RAC accurately. When using ANN to predict the compressive strength value of RAC, the maximum particle size of aggregate, water absorption and SSD specific density can generally reflect the properties of RA, however, the performance of ANN model can still be improved if more parameters can be considered, such as cement type and quality of the RA.

## CONCLUSION

In this paper, the artificial neural networks method was assessed to see whether it can be used to predict the compressive strength of RAC.

It can be concluded that;

(1) The maximum size of aggregates, water absorption values and SSD specific density can generally reflect the properties of RA.

(2) Artificial neural networks has good accuracy on predicting the strength of sustainable RAC.

(3) The performance of neural networks model is still to be improved with more parameters be considered in the further research.

It is interesting to know whether other properties of RAC, such as modulus of elasticity, durability, creep and shrinkage can be modeled as well by ANN. Further research should be undertaken to improve the ANN generalization ability.

## REFERENCES

1) Z.H. Duan, S.C. Kou, C.S. Poon , Prediction of compressive strength of recycled aggregate concrete using artificial neural networks, Construction and Building Materials 40 (2013) 1200–1206

2) Palika Chopra, Rajendra Kumar Sharma, and Maneek Kumar, Artificial Neural Networks for the Prediction of Compressive Strength of Concrete, International Journal of Applied Science and Engineering 2015. 13. 3: 187-204.

3) Jing-gan Shao1,a, Xiao-xiang Ji2,b and Ran Li2,c, Application of BP Neural Network Model in the Recycled Concrete Performance Prediction, International Conference on Advances in Energy, Environment and Chemical Engineering (AEECE-2015).

4) Vinay ChandwaniȦ*, Vinay AgrawalȦ and Ravindra NagarȦ, Applications of Artificial Neural Networks in Modeling Compressive Strength of Concrete: A State of the Art Review, International Journal of Current Engineering and Technology, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161, ©2014 INPRESSCO®, http://inpressco.com/category/ijcet.

5) Dr. Salim T. Yousif Salwa M. Abdullah, Artificial Neural Network Model for Predicting Compressive Strength of Concrete, Tikrit Journal of Eng. Sciences/Vol.16/No.3/September 2009, (55-66)

6) Kavya S. P1 Dr. M. N. Hegde2, Evaluation of the Strength of Recycled Aggregate Concrete using Artificial Neural Network, IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 05, 2015 | ISSN (online): 2321-0613.

**7)** A Torre1, F Garcia2, I Moromi1, P Espinoza3, L Acuña3, Prediction of compression strength of high performance concrete using artificial neural networks. VII International Congress of Engineering Physics , Journal of Physics: Conference Series 582 (2015) 012010

**8)** F. Alfin, Ashmita,S. Chithra, S.R.R. Senthil Kumar,K. Chinnaraju, Modeling Elastic Modulus of High Performance Concrete Using Artificial Neural Networks, International Conference on Explorations & Innovations in Engineering and Technology, ICEIET – 2016.

**9)** A.N .Dabhade1, Dr. S.R.Chaudhari2, Dr. A.R.Gajbhiye, Modelling Split Tensile Strength of Recycled Aggregate Concrete Using Regression and Neural Network, International Journal of Research in Advent Technology (E-ISSN: 2321-9637), "ICATEST 2015", 08 March 2015.

**10)** Abbas M Abd1 and Suhad M Abd, NEURO-FUZZY MODEL TO EVALUATE READY-MIX CONCRETE PROPERTIES, ISSN 2319-5991www.ijerst.com . Vol. 3, No. 1, February 2014

**11)** Behzad Abounia Omran, Qian, Ruoyu, Prediction of Compressive Strength of "Green" Concrete Using Artificial Neural Networks, 50th ASC Annual International Conference Proceedings. (2014)

**12)** Palika Chopra,1 Rajendra Kumar Sharma,1 and Maneek Kumar, Prediction of Compressive Strength of Concrete Using Artificial Neural Network and Genetic Programming, Hindawi Publishing Corporation, Advances in Materials Science and Engineering, Volume 2016, Article ID 7648467, 10 pages, http://dx.doi.org/10.1155/2016/7648467

**13)** Mehdi Nikoo,1 Farshid Torabian Moghadam,2 and Aukasz Sadowski3, Prediction of Concrete Compressive Strength by

Evolutionary Artificial Neural Networks, Hindawi Publishing Corporation, Advances in Materials Science and Engineering, Volume 2015, Article ID 849126, 8 pages, http://dx.doi.org/10.1155/2015/849126

**14)** Serkan Subaı, Prediction of mechanical properties of cement containing class C fly ash by using artificial neural network and regression technique, Scientific Research and Essay Vol. 4 (4) pp. 289-297, April, 2009, Available online at http://www.academicjournals.org/SRE

**15)** Vijay Pal Singh, Yogesh Chandra Kotiyal, Prediction of Compressive Strength Using Artificial Neural Network, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:7, No:12, 2013

**16)** Sakshi Gupta, Using Artificial Neural Network to Predict the Compressive Strength of Concrete containing Nano-silica, Civil Engineering and Architecture 1(3): 96-102, 2013, http://www.hrpub.org

**17)** Basil Johny, Prof. M.V. George, Dr. Elson John, "Study of Properties of Sustainable concrete using Slag and Recycled Concrete Aggregate"(2014), International Journal of Engineering Research and Technology, Vol. 3 Issue 9, September 2014.

**18)** Chetna M Vyas, Darshana R Bhatt, "Destructive Strength Properties of Recycled Coarse Aggregate"(2013), International Journal of Innovative Technology and Exploring Engineering, Volume 2, Issue 3, February 2013.

**19)** Myle Nguyen James, Wonchang Choi, Taher Abu-Lebdeh,(2011), Use of Recycled Aggregate and Fly Ash in Concrete Pavement, American Journal of Engineering and Applied Sciences 4 (2):201-208, 2011. Department of Civil, Architecture and Environmental

Engineering, North Carolina A and T State University, USA.

**20)** S. C. Kou, Chi s. Poon, Dixon Chan, Properties of Steam Cured Recycled Aggregate Fly Ash Concrete, Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

**21)** S. B. Singh, Mahalakshmi. N., Nikesh Thammishetti, “Mechanical Properties of Recycled Coarse Aggregate (RCA) Concrete.”(2014), Civil Engineering Department, BITS Pilani-333031, Rajasthan, India. International Journal of Applied Engineering Research, Volume 9, Number 3 (2014)

**22)** N. Sivakumar, S. Muthukumar, V. Sivakumar, D. Gowtham, V. Muthuraj, “Experimental Studies on High Strength Concrete by Using Recycled Coarse Aggregate”. Research Inventy: International Journal of Engineering And Science Vol.4, Issue 01 (January 2014), PP 27-36, Department of Civil Engineering, Jay Shriram Group of Institutions, Tirupur, TamilNadu, India.

**23)** Madan Mohan Reddy.K, Bhavani.R, Ajitha. B,”Local Construction And Demolition Waste Used As Coarse Aggregates In Concrete”(2012), International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, www.ijera.com, Vol. 2, Issue 5, September- October 2012.

**24)** Ravi Patel, Chetna M Vyas & Darshana R Bhatt, “Experimental Investigation For Recycled Coarse Aggregate Replaced For Natural Coarse Aggregate In Concrete”(2013). International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN 2249-6866 Vol. 3, Issue 2, Jun 2013.

**25)** Mirjana Malešev, Vlastimir Radonjanin and Snežana Marinković, “Recycled Concrete as Aggregate for Structural Concrete

Production". Sustainability 2010, 2, 1204-1225; doi:10.3390/su2051204 www.mdpi.com/journal/sustainability.

**26)** Akinkurolere O. O., "Effects of Rice-Husk Ash as Partial Replacement for Cement on Compressive Strength of Recycled Aggregate Concrete."(2013), International Journal of Engineering and Technology Volume 3 No. 8, August, 2013 Department of Civil Engineering, Faculty of Engineering, Ekiti State University, Ado-Ekiti, Nigeria.

**27)** Surya, M., Kanta Rao, Lakshmy P. , "Recycled aggregate concrete for Transportation Infrastructure", 2nd Conference of Transportation Research Group of India (2nd CTRG), Procedia - Social and Behavioral Sciences 104 ( 2013 ) 1158 – 1167, www.sciencedirect.com.

**28)** Mr. Tushar R Sonawane, Prof. Dr. Sunil S. Pimplikar, "Use of Recycled Aggregate Concrete." IOSR, Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684, PP: 52-59 www.iosrjournals.org.

**29)** Parekh D. N. and Dr. Modhera C. D., "Assesment Of Recycled Aggregate Concrete." Journal of Engineering Research and Studies, JERS/Vol.II/ Issue I/January-March 2011/1-9 Applied Mechanics Department; Sardar Vallbhbhai National Institute of Technology; Surat; Gujarat

**30)** S.C. Kou, C.S. Poon (2012), Enhancing the durability properties of concrete prepared with coarse recycled aggregate, Construction and Building Materials, 35, 69–76.

**31)** Shi-cong Kou, Chi-sun Poon, Francisco Agrela (2011), Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures, Cement & Concrete Composites, 33, 788–795

**32)** V.S.Babu, A.K.Mullick, K.K.Jain and P.K.Singh (2013), Mechanical properties of high strength concrete with recycled aggregate-influence of processing, The Indian Concrete Journal, 88, 10-26.

**33)** Hisham Qasrawi (2014), The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment, Construction and Building Materials, 54, 298–304.

**34)** Bibhuti Bhusan Mukharjee , Sudhirkumar V. Barai (2014), Influence of Nano-Silica on the properties of recycled aggregate concrete , Construction and Building Materials ,55, 29–37.

**35)** S R Yadav*, S R Pathak, USE OF RECYCLED CONCRETE AGGREGATE IN MAKING CONCRETE- AN OVERVIEW, 34th Conference on OUR WORLD IN CONCRETE & STRUCTURES: 16 – 18 August 2009, Singapore

**36)** Anagha Kalpavalli, Dr. S. M. Naik, Use of Demolished Concrete Wastes As Coarse Aggregates in High Strength Concrete Production, International Journal of Engineering Research & Technology (IJERT)ISSN:2278-0181,IJERTV4IS070935,Vol.4,Issue 07,July-2015,www.ijert.org

**37)** Poon CS, Shui ZH, Lam L, Fok H, Kou SC. Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete. Cem Con Res 2004;34(1):31–6.

**38)** Poon CS, Kou SC, Lam L. Influence of recycled aggregate on slump and bleeding of fresh concrete. Mater Struct 2007;40(9):981–8.

**39)** Zega CJ, Maio AAD. Recycled concrete made with different natural coarse aggregates exposed to high temperature. Constr Build Mater 2009;23(5):2047–52.

**40)** Yong HL, Yaw TY, Ta CP, Ching YC. An assessment of optimal mixture for concrete made with recycled concrete aggregates. Cem Concr Res 2004;34(8):1373–80.

**41)** Cabo AD, Lázaro C, Gayarre FL, López MAS, Serna P, Tabares JOC. Creep and shrinkage of recycled aggregate concrete. Constr Build Mater 2009;23(7):2545–53.

**42)** Soberón JG. Porosity of recycled concrete with substitution of recycled concrete aggregate: an experimental study. Cem Concr Res 2002;32(8):1301–11.

**43)** Fonteboa BG, Abella FM. Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties. Build Environ 2008;43(4):429–37.

**44)** de Juan MS, Gutiérrez PA. Influence of recycled aggregate quality on concrete properties. In: Conference on use of recycled materials in building and structures. 9–11 November, 2004, Barcelona, Spain [Abstract ID Number: 347]

**45)** Kou SC, Poon CS. Effect of quality of parent concrete on the mechanical properties of high performance recycled aggregate concrete. In: Submitted to the 9th symposium on high performance concrete design, verification & utilization, Christchurch, New Zealand, 9–11, August 2011.

**46)** Faiz A. M. Mirza1 and Mohammed A. Saif, Mechanical Properties of Recycled Aggregate Concrete Incorporating Silica Fume, Second International Conference on Sustainable Construction materials and Technology.(2010), http://www.claisse.info/Proceedings.htm. Mill Valley, CA: University Science, 1989.