Influence of Coarse Aggregate Gradation on the Mechnical Properties of Concrete, Part I: No-Fines Concrete

Zaheer Ahmed Tunio
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology,
Nawabshah, Pakistan
zaheerahmedtunio@gmail.com

Fahad-ul-Rehman Abro
Department of Civil engineering,
Mehran University of Engineering and Technology,
Jamshoro, Pakistan
fahad.abro@gmail.com

Tariq Ali
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology,
Nawabshah, Pakistan
tariqdehraj@gmail.com

Abdul Salam Buller
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology,
Larkana Campus, Pakistan
buller.salam@quest.edu.pk

Muhammad Ali Abbasi
Department of Civil Engineering,
Quaid-e-Awam University of Engineering,
Science & Technology, Nawabshah, Pakistan
maliengrs@gmail.com

Abstract—**It is an accepted fact that in concrete construction, the self-weight of the structure is a major part of its total load. Reduction in the unit weight of the concrete results in many advantages. Structural lightweight aggregate concrete (LWAC) of adequate strength is now commonly used. In frame structures, the partition walls are free of any loading, where the construction of these non-structural elements with lightweight concrete of low strength would lead to the subsequent reduction of the overall weight of the structure. No-fines concrete is one of the forms of lightweight concrete and it is porous in nature. It can be manufactured similarly as normal concrete but with only coarse aggregates and without the sand. Thus, it has only two main ingredients, the coarse aggregates, and the cement. The coarse aggregates are coated with a thin cement paste layer without fine sand. The current paper is a report of a detailed experimental study carried on NFC with fixed cement to aggregate proportion of 1:6 with 0.40 w/c (water-cement) ratio. Coarse aggregate of various gradations(7mm-4.75mm, 10mm-4.75mm, 10mm-7mm, 13mm-4.74mm, 10mm-7mm, 13mm-4.75mm, 13mm-10mm, 13mm-7mm, 20mm-4.75mm, 20mm-7mm, 20mm-10mm, 20mm-13mm), were used. Specimens of standard sizes were cast to determine the compressive and splitting tensile strength after the specimens were cured in water up to the age of testing (28 days).**

Keywords-no-fines; cement to aggregate mix proportion; unit weight; compressive strength; splitting tensile strength

I. Introduction

Concrete resulting by removing fine aggregates from normal concrete is termed as no-fines concrete (NFC), which is classified as a type of lightweight porous concrete. Gravels known as coarse aggregates are coated with a thin layer of cement paste with no fine particles thus showing a two-phase material system. The coarse material is connected with a point-to-point network system with a small fillet of cement paste, holding particles together and giving strength to concrete [1]. NFC is usually used in parking areas [2], partition walls [3], as a contamination deterrent [4], in parking lots [5], and as brick material [6]. NFC pavements provide storm water management [7, 8] allowing water and air to percolate underground [9, 10]. Generally, NFC has aggregate-cement ratios ranging from 6:1 to 10:1. Normally NFC has w/c ranging from 0.28 to 0.40 [11]. In [11], it was concluded that the highest strengths were obtained with an aggregate-cement ratio of 7:1 and it has been concluded that when cement-aggregate ratio is increasing the strength properties are decreasing. The tensile and flexural strengths of NFC were significantly lower than those obtained from conventional concrete [12, 13]. The strength of NFC is less than normal concrete's because of the existence of more voids with in its body [14]. NFC is different from conventional concrete which includes no-fine aggregates in the mixture. The coarse aggregates are combined with low water content with w/c ratio within the range of 0.25 to 0.35 for making NFC mixture with void contents ranging from 11% to 35% which results to high water and air permeability [15-17]. Previously, NFC was developed with only one size of coarse aggregate gradation: 20mm-10mm, maintained by appropriate sieves [15]. The current study shows the influence of coarse aggregate gradation on the mechanical properties of NFC with different sizes of gravel.

II. Experimental Methodology

The main aim of this study is to investigate the compressive and splitting tensile strength of no-fines concrete. The cement-aggregate (c-a) proportions 1:6 of NFC were adopted. Twelve

Corresponding author: Abdul Salam Buller

different coarse aggregate gradations were used (details in Table I). The NFC is cast with 0.4 w/c ratio. Ordinary Portland cement (OPC) as per standard of ASTM C150 was used to manufacture the NFC and NC and cast the specimens of both concretes. The crushed stones used as coarse aggregates were obtained from the local market. They were washed and air dried and then they were sieved accordingly to achieve the specified aggregate gradations. Potable water was used for casting and curing of the specimens. All the ingredients of each mix were batched accordingly following the proper mixing in an electric operated mixer. A total number of 60 cube specimens for NFC of standard size 150mm×150mm×150 mm, and 60 cylinders for NFC of standard size 150mm×300mm were cast. The specimens were demoulded after 24 hours of casting and were kept in a curing tank up to the age of testing. Wet curing was applied. All specimens were tested after 28 days of curing.

TABLE I. BATCHES DETAILS

S. No.	Aggregate gradation (max-min)* (mm)
01	7-4.75
02	10–4.75
03	10–7
04	13–4.75
05	13–7
06	13–10
07	20–4.75
08	20–7
09	20–10
10	20–13

*NFC with gravel varying between max and min in mm.

III. RESULTS AND DISCUSSION

A. Compressive Strength of NFC

The cubes were tested to measure the compressive strength of concrete. Compressive strength tests were conducted in a Universal Testing Machine (UTM). The cubes were placed between the plates of UTM and then load was applied gradually until the cubes were crushed. The load at crushing failure was recorded. The load is divided by the cross sectional area of the cube to determine the ultimate compressive stress using (1). The results of the average compressive strength are presented in Table II.

$$f_{cu} = \frac{P}{A} \quad (1)$$

B. Splitting Tensile Strength of NFC

Split cylinder test was carried out to measure the tensile strength of concrete. The cylinders were placed horizontal between two plates in the UTM and load was applied gradually on the center of the cylinder until failure. The load at failure was recorded and calculations were made with (2) to determine tensile strength. The results of the average splitting tensile strength are presented in Table III.

$$f_t = \frac{2P}{\pi LD} \quad (2)$$

C. Unit Weight

In the unit weight test, the weight of the specimens was recorded before testing. The results are presented in Table IV. From Table IV, it is obvious that coarse gradation affects the unit weight of NFC. NFC with coarse aggregate gradation of 7mm-4.75mm had maximum density equal to 2089kg/m^3, and with coarse aggregate gradation 13mm-10mm had the lowest, which was 1754kg/m^3. The average unit weight of NFC was found to be 1883kg/m^3. It may be observed that unit weight of NFC increases with the widening range of coarse aggregates.

TABLE II. AVERAGE COMPRESSIVE STRENGTH OF NFC

S. No.	Aggregate gradation (mm)	Average compressive strength f_{cu}	
		MPa	psi
01	7–4.75	7.31	1059.95
02	10–4.75	4.27	619.15
03	10–7	11.12	1612.40
04	13–4.75	7.23	1048.35
05	13–7	6.87	996.15
06	13–10	3.29	477.05
07	20–4.75	4.66	675.70
08	20–7	7.56	1096.20
09	20–10	6.94	1006.30
10	20–13	5.17	749.65
Maximum: 10–7		11.12	1612.40
Minimum: 13–10		3.29	477.05

TABLE III. AVERAGE SPLITTING TENSILE STRENGTH OF NFC

S. No.	Aggregate gradation (mm)	Average tensile strength f_t	
		MPa	psi
01	(7– 4.75)	0.85	123.25
02	(10–4.75)	1.02	147.90
03	(10–7)	0.92	133.40
04	(13–4.75)	1.23	178.35
05	(13–7)	1.13	163.85
06	(13–10)	0.89	129.05
07	(20–4.75)	1.28	185.60
08	(20–7)	1.26	182.70
09	(20–10)	1.08	156.60
10	(20–13)	1.05	152.25
Maximum: 20–4.75		1.28	185.6
Minimum: 7-4.75		0.85	123.3

TABLE IV. AVERAGE UNIT WEIGHT OF NFC

S. No.	Aggregate gradation (mm)	Average unit weight (Kg/m^3)
01	7–4.75	2089
02	10–4.75	1820
03	10–7	1760
04	13–4.75	2021
05	13–7	1909
06	13–10	1754
07	20–4.75	1760
08	20–7	2009
09	20–10	1852
10	20–13	1852
Maximum: 7–4.75		2089
Minimum: 13–10		1754

Fig. 1. A cubic specimen before and after testing in UTM

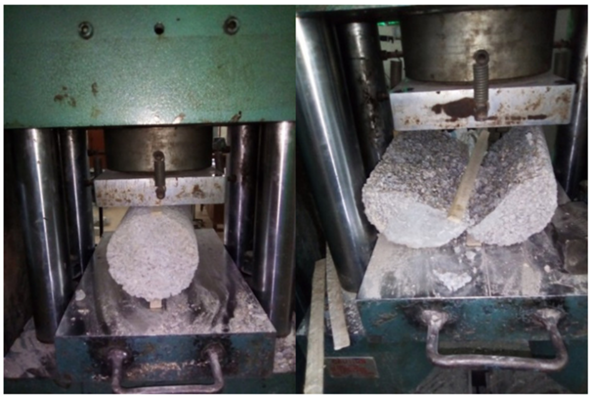

Fig. 2. A cylinder specimen before and after testing in UTM

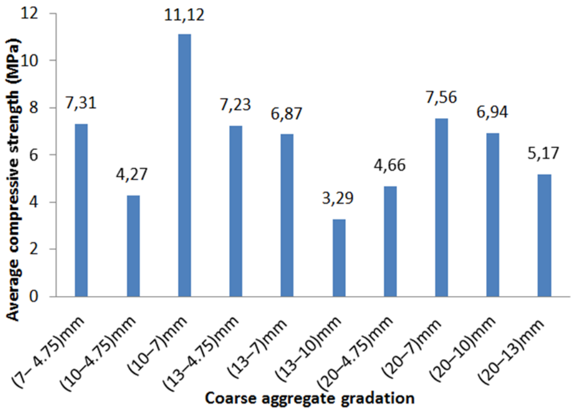

Fig. 3. Compressive strength with various aggregate gradations and 1:6 c-a proportion at 0.4 w/c ratio

It has been observed that the aggregate gradation significantly affects the compressive strength of concrete. The maximum compressive strength of NFC is 11.12MPa with 10mm-7mm size of coarse aggregate gradation, whereas the lowest compressive strength of NFC was 3.29MPa with 13mm-10mm range of coarse aggregate gradation. The compressive strength of NFC with coarse aggregate gradation of 10mm-7mm is increased by 51.12%, 162%, 52.12%, 61.86%, 236.62%, 47.08%, 60.23%, 115.08%, 120% as compared to gradation of 7-4.75, 10-4.75, 13-4.75, 13-7, 13-10, 20-4.75, 20-7, 20-10, and 20-13 respectively (in mm). It may be concluded that while producing the NFC, the gradation of the coarse aggregates may be considered properly if the compressive strength is a major parameter. Like the compressive strength of NFC, its tensile strength is also greatly affected by the gradation of the coarse aggregates used. The maximum split tensile strength of NFC obtained was 1.29MPa with 20mm-4.75mm size of coarse aggregate gradation and the minimum was 0.85MPa for the 13mm-10mm coarse aggregate gradation. The split tensile strength of NFC with coarse aggregate gradation of 20mm-4.75mm is increased by 50.58%, 25%, 39.13%, 4.06%, 13.27%, 43.82%, 1.58%, 18.5%, 20.9% for gradation of 7-4.75, 10-4.75, 10-7, 13-4.75, 13-7, 13-10, 20-7, 20-10, and 20-13mm, respectively.

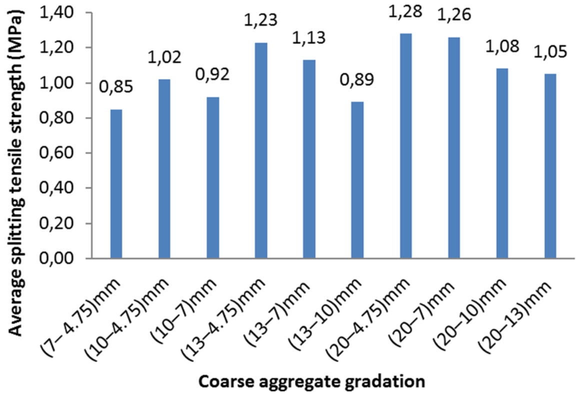

Fig. 4. Splitting tensile strength with various aggregate gradation and 1:6 c-a proportion at 0.4 w/c ratio

IV. Conclusions

Different gradations of coarse aggregate were used in NFC, and the effects on unit weight, compressive strength and tensile strength were studied. The results may be summarized as:

- The maximum obtained unit weight was 2089kg/m^3 for NFC with aggregate gradation range of 7mm-4.75mm. The minimum obtained unit weight was 1.574kg/m^3 for NFC with aggregate gradation range of 13mm-10mm. The average unit weight was 1882.1882kg/m^3 which is approximately 21% of that of normal weight concrete which is 2400kg/m^3.
- The variation in the compressive strength of NFC due to coarse aggregate gradation ranged from 11.12Mpa to 2.93Mpa exhibited with N.F.C of coarse aggregate gradations of 10mm-4.75mm and 13mm-10mm respectively.
- The tensile strength of N.F.C due to the different coarse aggregate gradations ranges between 0.85Mpa-1.28Mpa.
- The behavior of NFC with various coarse aggregate gradations in terms of compressive strength and tensile strength is different because the compressive strength of NFC with 10mm-7mm coarse aggregate gradation is maximum whereas the tensile strength of NFC with coarse aggregate gradation of 20mm-4.75mm is minimum.

- The behavior of NFC with 7mm-4.75mm, 13mm-4.75mm, and 20mm-7mm coarse aggregate gradations in terms of compressive strength is approximately similar.
- The behavior of NFC with 13mm-4.75mm and 20mm-7mm coarse aggregate gradations in terms of tensile strength is approximately similar.
- It is observed from the results that coarse aggregate gradation has considerable effects on the compressive and tensile strength of concrete.
- The relationship of NFC with various coarse aggregate gradations in terms of compressive strength and split tensile is different as compared to normal concrete.

Based on the results of this experimental study, it may be concluded that while producing NFC, the gradation of aggregates, c-a ratio and w/c ratio may be chosen appropriately particularly when the compressive strength is the major parameter of consideration. However, to a limited extent, unit weight and apparent texture also depend upon these factors.

ACKNOWLEDGMENT

The authors are grateful to the Quaid-e-Awam University of Engineering, Science and Technology for providing the research facilities.

REFERENCES

[1] B. Alam, M. Javed, Q. Ali, N. Ahmad, M. Ibrahim, "Mechanical properties of no-fines bloated slate aggregate concrete for construction application, experimental study", International Journal for Computational Civil and Structural Engineering, Vol. 3, No. 2, pp. 302-312, 2012

[2] R. Lomte, "A review on study and analysis of strength, permeability and void ratio of pervious concrete", International Journal for Research in Applied Science & Engineering Technology, Vol. 6, No. 1, pp. 1717-1720, 2018

[3] A. Muneeb, M. A. Memon, M. A. Bhutto, A. Lakho, I. A. Halepoto, A. N. Memon, "Effects of uncrushed aggregate on the mechanical properties of no-fines concrete", Engineering, Technology & Applied Science Research, Vol. 8, No. 3, pp. 2882-2886, 2018

[4] S. Ali, S. Kacha, "Correlation among properties of no fines concrete–A review", International Journal of Advance Engineering and Research Development, pp. 87-91, 2017

[5] G. Yuvaraj, K. Sundaravadivelu, P. Vembuli, R. Shankaranarayanan, E. Ramya, "A study on compressive strength of pervious concrete by varying the size of aggregate", International Journal of Engineering Science and Computing, Vol. 7, No. 4, pp. 10149-10152, 2017

[6] K. B. Thombre, A. B. More, S. R. Bhagat, "Investigation of strength and workability in no-fines concrete", International Journal of Engineering and Technical Research, Vol. 5, No. 9, pp. 390-393, 2016

[7] G. Divya, L. Reena, "An experimental stduies on behaviour of pervious concrete by using addition of admixtures", International Research Journal of Engineering and Technology, Vol. 4, No. 3, pp. 2366-2370, 2017

[8] P. P. Pragnya, K. B. Parikh, A. R. Darji, "A review on experimental investigation of pervious concrete using alternate materials", Journal of Emerging Technologies and Innovative Research, Vol. 4, No. 3, pp. 68-70, 2017

[9] C. H. S. Priyanka, "Experimental analysis on high strength pervious concrete", International Journal of Advances in Mechanical and Civil Engineering, Vol. 4, No. 2, pp. 9-13, 2017

[10] U. M. Muthaiyan, S. Thirumalai, "Studies on the Properties of Pervious Fly Ash–Cement Concrete as a Pavement Material", Civil & Environmental Engineering, Vol. 4, No. 1, Article ID 1318802, 2017

[11] K. R. Balsaraf, D. R. Kurhade, K. A. Varpe, N. S. Lohote, D. S. Mehetre, "A review paper on no fines concrete", International Journal Of Engineering Sciences & Management, Vol. 7, No. 1, pp. 293-303, 2017

[12] M. Kovac, A. Sicakova, "Pervious Concrete as a Sustainable Solution for Pavements in Urban Areas", 10th International Conference Environmental Engineering, Vilnius, Lithuania, April 27-28, 2017

[13] D. S. Shah, J. Pitroda, "An experimental study on durability and water absorption properties of pervious concrete", International Journal of Research in Engineering and Technology, Vol. 3, No. 3, pp. 439-444, 2014

[14] I. Barisic, M. Galic, I. N. Grubesa, "Pervious Concrete Mix Optimization for Sustainable Pavement Solution", IOP Conference Series: Earth and Environmental Science, Vol. 90, Article ID 012091, 2017

[15] M. Nallanathel, B. Ramesh, P. H. Vardhan, "Effect of water cement ratio in pervious concrete", Journal of Chemical and Pharmaceutical Sciences, Vol. 6, pp. 200-203, 2017

[16] K. B. Thombre, A. B. More, S. R. Bhagat, "Investigation of strength and workability in no-fines concrete", International Journal of Engineering Research & Technology, Vol. 5, No. 9, pp. 390-393, 2016

[17] W. T. Kuo, C. C. Liu, D. S. Su, "Use of washed municipal solid waste incinerator bottom ash in pervious concrete", Cement and Concrete Composites, Vol. 37, pp. 328-335, 2013

[18] M. A. Alam, S. Naz, "Experimental study on properties of no-fine concrete", International Journal of Informative & Futuristic Research, Vol 2, No. 10, pp. 3687-3694, 2015