ARTICLE IN PRESS

Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Engineering properties of concrete with partial utilization of used foundry sand

Thiruvenkitam Manoharan [a,*], Dhamothiran Laksmanan [b], Kaliyannan Mylsamy [c], Pandian Sivakumar [d], Anirbid Sircar [d]

[a] Department of Mechatronics, RVS Technical Campus, Coimbatore 641402, India
[b] Faculty of Engineering, Karpagam Academy of Higher Education, Coimbatore 641021, India
[c] Department of Mechanical Engineering, Dr. N.G.P. Institute of Technology, Coimbatore 641 048, India
[d] School of Petroleum Technology, Pandit Deendayal Petroleum University, Gandhinagar 382007, India

ARTICLE INFO

Article history:
Received 19 February 2017
Revised 6 October 2017
Accepted 19 October 2017
Available online xxxx

Keywords:
River Sand
Used Foundry Sand
Concrete
Sodium Silicate

ABSTRACT

Solid wastes generated from manufacturing industries are increasing at an alarming rate and it is consistently increasing. One such industrial solid waste is Used Foundry Sand (UFS). On the other hand, fine aggregates involved in the concrete are generally river sand, which is scarce, high cost and excavation of the river sand that promote environmental degradation. So, there is an urge to find some alternative solution to dispose UFS and to limit the use of river sand. In this research work, river sand was partially replaced by UFS. The percentage replacements were 0, 5, 10, 15, 20 and 25 wt% respectively. Experimental investigations were carried out to evaluate the mechanical, durability and microstructural properties of M20 concrete at the age of 7, 28 and 91 day. XRD (X-ray Diffraction), EDX (Energy Dispersive X-ray) and optical-microscopic imaging analysis were performed to identify the presence of various compounds and micro cracks in the concrete with UFS. Comparative studies on control mix against trial mix were carried out. It was found that compression strength, flexural strength and modulus of elasticity were approximately constant up to 20 wt% UFS and decreased with further addition. Whereas, split tensile strength was increased after 20 wt% addition but it affects the other properties of concrete. The durability test results showed that the resistance of concrete against abrasion and rapid chloride permeability of the concrete mixture containing UFS up to 20 wt% were almost similar to the values of control mix. The findings suggest that UFS can effectively replace river sand. However, it is recommended that the replacement should not exceed 20 wt%.

1. Introduction

The use of concrete in the development of architecture and constructions is an integral part of modern human civilization. The key constituents of modern concrete are cement, river sand and aggregate which play significant roles in mix design. Since the consumption of river sand is high in the rapid infrastructure growth, the demand for the same is also very high in developing countries. Replacing river sand, either partially or fully, is being investigated as an approach to tackle this problem. Replacement of this component is a key challenge to address the negative effect of this substitution, which is mainly related to strength development in concrete (Neramitkornburi et al., 2015). Waste materials like recycled demolition materials, slag, foamed recycled glass, calcium carbide residue, UFS, fly ash, etc. are already being used as supplementary cementitious materials and have been studied in recent decades (Arulrajah et al., 2015; Phetchuay et al., 2014; Rahman et al., 2015). Among these materials, the use of UFS has not been researched considerably and it still remains an unexplored area in terms of its use as a supplement for river sand (Arulrajah et al., 2017). Therefore, studies on the potential use of these replacements are ultimately important.

UFS from ferrous and non-ferrous metal casting industries are mostly discarded as land filling material or dumped in open baron lands (Saraswati et al., 2013; Md et al., 2013; Amritkar et al., 2015). In contrast several countries have facing the problem in the supply of river sand to meet the increasing construction requirements (Bahoria et al., 2013; Prabhu et al., 2015). UFS creates nuisance to the public by the means of air and water pollution. Because of increased urbanization, scarcity of lands for disposal, stringent government rules and regulations, awareness of the public,

* Corresponding author.
E-mail address: manoharanpark@gmail.com (T. Manoharan).

https://doi.org/10.1016/j.wasman.2017.10.022
0956-053X/© 2017 Published by Elsevier Ltd.

increased transportation cost makes it very difficult for conventional disposal of foundry sand. It is an alarming issue for the sustainability of the metal casting industries and environment. So it is very crucial to find out the solution to utilize the used foundry sand and to reduce the sand extraction from the river bed. There are different types of binders were used in the foundry industry to bind the sand particles. The widely used binders were clay bonded sand and chemically bonded sand. In this research work, UFS in the form of chemically bonded sand (sodium silicate) was used for the experimental investigations.

A few researchers had investigated the fresh and hardened properties of concrete containing clay bonded UFS to know the possibility of replacement of river sand in concrete. They concluded that, it is possible to replace the fine aggregate but the amounts of replacements were varied (Singh and Siddique, 2012a, 2012b; Siddique et al., 2009). This is due to the type and amount of binder used in the molding sand which influences the physical properties to a great extent.

The potential applications of UFS can be subdivided into three main categories namely, recycling, geotechnical and soil-based applications. Among the above, geotechnical applications have the huge scope for utilizing enormous quantity of UFS coming out from the foundries. The benefit of replacing UFS in concrete helps to reduce environmental and economic impacts (Prabhu et al., 2015; Singh and Siddique, 2012a). This promotes the sustainability of the foundry industries.

This research paper discuss the experimental results conducted for the evaluation of fresh concrete properties, mechanical properties (compressive strength, splitting tensile strength, flexural strength and modulus of elasticity), durability properties (ultrasonic pulse velocity, rapid chloride permeability, water absorption and abrasion resistance) and micro-structural analysis, after partially replacing natural fine aggregate by UFS.

2. Materials and methods

2.1. Cement

Portland pozzolana cement 53 Grade of Ultratech brand single lot was used throughout the investigation. The cement used was fresh and without any lumps. The physical and chemical properties satisfy the requirements of IS: 8112-1989.

2.2. Aggregates

Natural river sand with 4.75 mm maximum size and machine crushed granite blue metal of 20 mm maximum size from the local crusher industry were used as fine and coarse aggregate respectively. Both aggregates were free from impurities such as dust, clay particles, organic matter etc, and tested as per IS: 383-1970. The physical properties of UFS, fine and coarse aggregates were given in Table 1.

Table 1
Physical properties of UFS, fine and coarse aggregates.

Parameters	UFS	Fine aggregate	Coarse aggregate
Moisture content (%)	0.60	0.33	0.55
Bulk density (kg m^{-3})	1811	1710	1640
Specific gravity	2.36	2.62	2.76
Fineness modulus	2.37	2.60	7.12
Water absorption (%)	0.90	1.13	0.70
Clay and friable particles (%)	1.4	–	–
Material finer than 150 μm (%)	1.1	3.9	Nil

2.3. Used foundry sand

Sample of the used chemically bonded foundry sand (sodium silicate) was collected in bags from local foundry located in Coimbatore, Tamilnadu. UFS was washed with fresh water for three times to remove the fines and clay particles. Then it was dried in sunlight for two days and used in concrete mixtures. The physical properties and particle size of the UFS used in this experimental work were given in Tables 1 and 2 respectively.

2.4. Water

Locally available potable water free from oils, acids, alkalis, salts and organic materials were used for mixing and curing.

2.5. Mix proportions

Concrete mixes were prepared in power driven roller mixer of capacity 0.76 cum, six different concrete mix proportions were made, in this first was the control mix and the other five mixes contained UFS. Fine aggregate was replaced with UFS by weight percentage. The fine aggregates replaced were 5, 10, 15, 20 and 25 wt%. The obtained mix-proportions were 1:1.53:3.13 with water cement ratio 0.5 as per the IS: 10262-1982 and were given in Table 3.

2.6. Sizes of the specimens used for evaluating the test results

All the specimens used in the experimental work were recommended by IS: 516-1959, cubical molds of size 150 × 150 mm were used for finding compressive strength and ultrasonic pulse velocity. Cylindrical moulds of 150 mm dia and 300 mm length, concrete specimens were prepared for the determinations of split tensile strength and modulus of elasticity. Beams having a size of 100 × 100 × 500 mm were prepared to evaluate the flexural strength of the concrete. The cylinders (100 mm diameter and 200 mm length) were cast for rapid chloride penetration resistance test.

The number of concrete samples tested for each test was three specimens from each batch-mix. However, the individual result variation of a set of specimen should not be more than 15% of the average. If more, the test result of the sample was not considered and the test was repeated. The mean value obtained from these specimens was used to evaluate mix design.

2.7. Microstructure analysis

The micro structural and chemical compositions of the samples were examined by using the JEOL JSM6360LV SEM and EDX instrument. XRD peak intensities were used to determine the chemical combination and phase present in the system. This was done by using SHIMADZU XRD-6000. Optical image data of the surface measures the absorption and scattering properties of the structure under investigation. High-definition digital camera was employed to capture the images of 1 μm resolution, which were instantly transferred to a computer for digital image processing.

3. Results and discussions

3.1. Fresh concrete properties

Fresh concrete properties such as slump, compaction factor, fresh concrete density, air content and temperature were determined according to the Indian Standard Specification IS: 1199-1959. The results were presented in Table 4.

Please cite this article in press as: Manoharan, T., et al. Engineering properties of concrete with partial utilization of used foundry sand. Waste Management (2017), https://doi.org/10.1016/j.wasman.2017.10.022

Table 2
Sieve analysis of UFS.

IS sieve size	Weight retained (g)	Weight retained (%)	Cumulative percentage	Percentage of passing
4.75 mm	0	0	0	100
2.36 mm	45	4.50	4.50	95.50
1.18 mm	62	6.20	10.70	89.30
600 μm	165	16.50	27.20	72.80
300 μm	688	68.80	96.00	4.00
150 μm	29	2.90	98.90	1.10
Pan	11	1.10	100	0
Fineness modulus of UFS = 237/100 = 2.37				

Table 3
Mix design proportions (M20).

Materials	CM1-0	TM1-5	TM1-10	TM1-15	TM1-20	TM1-25
Cement (kg m^{-3})	394	394	394	394	394	394
River sand (kg m^{-3})	604	573.8	543.6	513.4	483.2	453
UFS (%)	0	5	10	15	20	25
UFS (kg m^{-3})	0	30.20	60.4	90.6	120.8	151
Coarse aggregate (kg m^{-3})	1235	1235	1235	1235	1235	1235
Water to cement volume ratio	0.50	0.50	0.50	0.50	0.50	0.50
Water (kg m^{-3})	197	197	197	197	197	197

Table 4
Fresh concrete properties.

Mixture no/concrete property	CM1-0	TM1-5	TM1-10	TM1-15	TM1-20	TM1-25
Slump (mm)	110	100	100	90	85	80
Compaction factor	0.94	0.94	0.92	0.90	0.90	0.90
Fresh concrete density (kg m^{-3})	2373	2372	2369	2366	2360	2355
Air content (%)	5.2	5.3	5.4	5.5	5.6	5.7
Air temperature (°C)	27	27	28	28	28	27
Concrete temperature (°C)	26	28	28	27	28	27

3.2. Hardened concrete properties

3.2.1. Mechanical properties of concrete

3.2.1.1. Compressive strength. The compressive strength results at 7, 14, 21 and 28 day cured M20 concrete with varying percentages of replaced UFS is shown in the Fig. 1. The 28 day results of control (0 wt% UFS) and trial mixture (20 wt% UFS) were 24.8 and 26.5 MPa respectively. Compressive strength of concrete mixtures made with UFS up to 20 wt% exhibit almost equal value as that of control mix. However, trial mix (TM1-25) were shown lesser strength compared to the CM1-0 mix this could probably due to increase in surface area of fine particles lead to the reduction of water cement gel in matrix so, the binding process of coarse and fine aggregate does not take place properly (Singh and Siddique, 2012a; Siddique et al., 2015). From these results, the UFS can be successfully used as a partial replacement of fine aggregate up to 20 wt%.

3.2.1.2. Split tensile strength. The split tensile strength results at 7 and 28 day of cured M20 concrete with varying percentages of replaced used foundry sand is shown in Fig. 2. The 28 day results of control (CM1-0) and trial mixture (TM1-20) where 2.2 and 2.8 N mm^{-2} respectively. The splitting tensile strength of concrete mixtures made with UFS up to 20 wt% show just about the value as that of control concrete. When the substitution amount was beyond 20 wt% reduction was observed. The trend is similar to that of compressive strength; similar results were reported by Siddique et al. (2009).

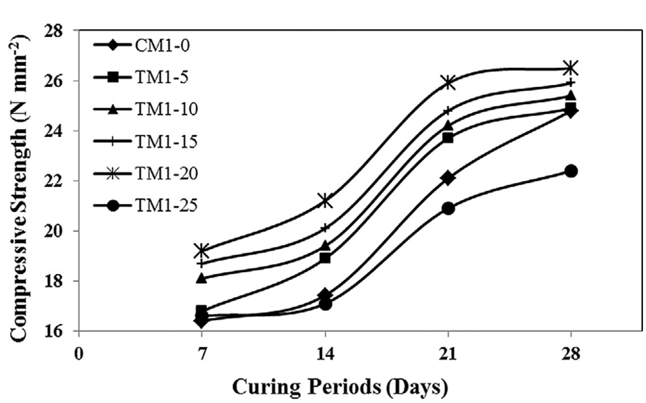

Fig. 1. UFS replacement Vs Compressive strength.

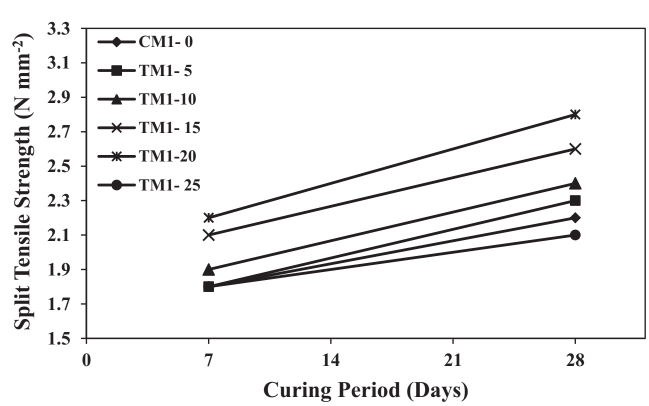

Fig. 2. UFS replacement Vs Split tensile strength.

Please cite this article in press as: Manoharan, T., et al. Engineering properties of concrete with partial utilization of used foundry sand. Waste Management (2017), https://doi.org/10.1016/j.wasman.2017.10.022

3.2.1.3. Flexural strength. The flexural strength results of 28 day cured concrete with varying percentages of replaced UFS are shown in Fig. 3. The 28 day results of control (0 wt% UFS) and trial mixture (20 wt% UFS) were 4.84 and 5.20 M Pa respectively. From these results, the flexural strength of concrete mixtures made with UFS up to 20 wt% reveal approximately equal value as that of the control mix. However, the trial mix TM1-25 was shown lesser strength compared to the CM1-0 mix, it could be probably due to the packing behavior between the particles. No more fine particles required for filling the voids between the particles. Similar results were reported by Siddique et al., (2009). From these results the UFS can be successfully used as a partial replacement of fine aggregate up to 20 wt%.

3.2.1.4. Modulus of elasticity. The modulus of elasticity results of 28 day cured concrete with varying percentages of replaced used foundry sand is shown in Fig. 4. The 28 day results of control (0 wt% UFS) and trial mixture (20 wt% UFS) were 23.6 and 25.4 GPa respectively. The modulus of elasticity of concrete mixtures increased with the increase in UFS up to 20 wt% replacement. When it was increased beyond, the reduction in elasticity was observed. This tendency is similar to that of compressive strength, splitting tensile strength and flexural strength. Similar results were reported by Siddique et al., (2009). From these results the UFS can be successfully used as a partial replacement of fine aggregate up to 20 wt%.

3.2.2. Durability properties of concrete

3.2.2.1. Ultra sonic pulse velocity. The ultra-sonic pulse velocity results of 28 day cured M20 concrete with varying percentages of replaced used foundry sand is shown in Fig. 5. The results of control (0 wt% UFS) and trial mixture (20 wt% UFS), were 4045 and 4090 ms^{-1} respectively at the age of 28 day. It could be probably due to the packing behavior between the particles. The ultrasonic pulse velocity increased with increase the replacement of UFS. This implies density, homogeneity and uniformity of concrete. Since ultrasonic wave took less time to reach the receiving end, a result pulse velocity increased.

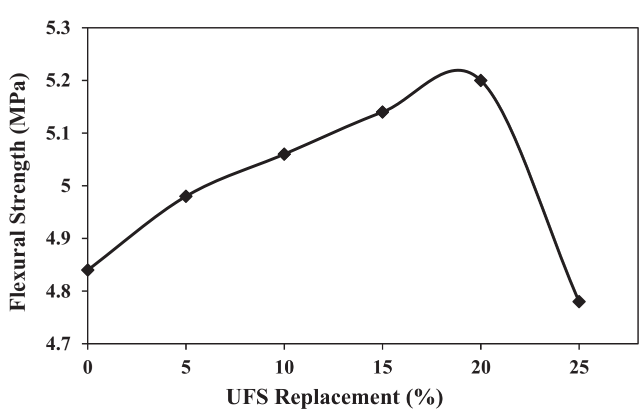

Fig. 3. UFS replacement Vs Average flexural strength at 28 day.

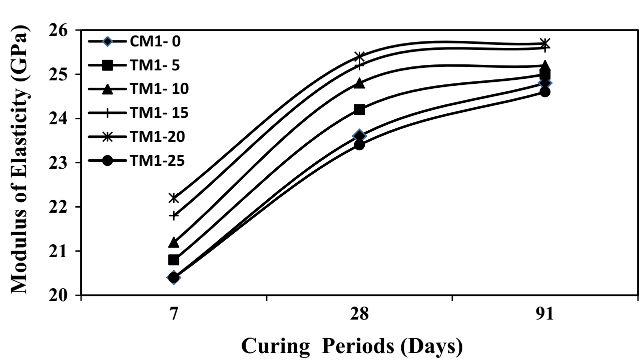

Fig. 4. UFS replacement Vs Modulus of elasticity.

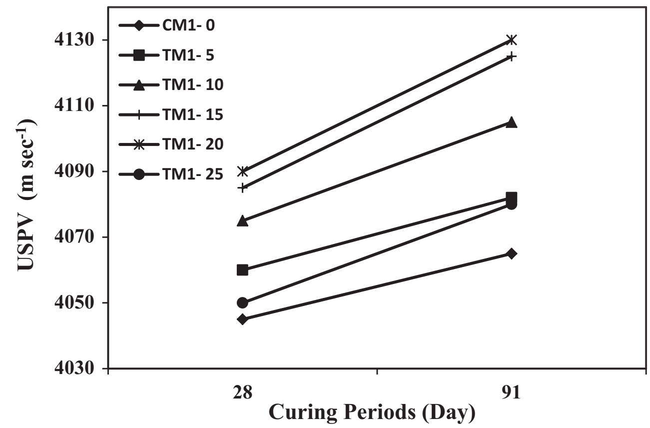

Fig. 5. UFS replacement Vs Ultra sonic pulse velocity (USPV).

3.2.2.2. Rapid chloride penetration test results. The rapid chloride penetration test results of 28, 56 and 91 day cured M20 concrete with varying percentages of replaced UFS is shown in Fig. 6. The 28-day rapid chloride penetration of control mixture (CM1-0) and trial mixture (TM1-20) were 1540 and 1250 Coulomb. Concrete mix TM1-20 (20 wt%) exhibit more resistance to chloride ion penetrability than control mix CM1-0 (0 wt% UFS), When it was increased to 25 wt%, slight increase in coulomb was observed, this is because the concrete becomes denser due to increase in fine particles. It could be probably due to the packing behavior between the particles due. Even though the concrete exhibit good strength at higher mix ratios the optimum mix was considered as 20 wt% which does not affect the other parameters.

3.2.2.3. Water absorption. Water absorption test results for 28 day cured concrete with varying percentages of replaced UFS was shown in Fig. 7. The 28 day water absorption of the control mixture (0 wt% UFS) and the trial mixture (20 wt% UFS) were 1.84 and 1.86% respectively. These results imply that the incorporation of UFS up to 20 wt% replacement not adversely influence on porosity of the concrete. When it was increased beyond slight increase in

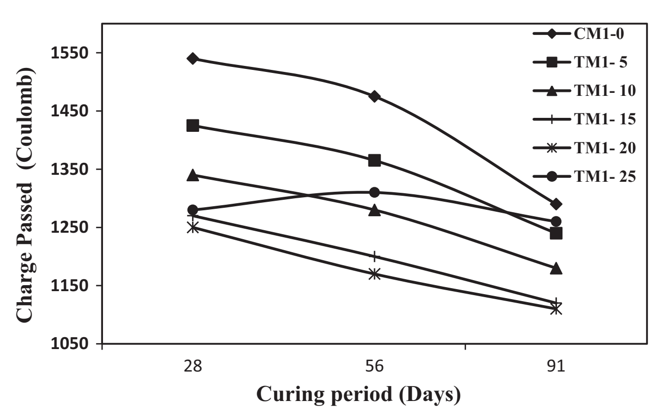

Fig. 6. UFS replacement Vs Charge passed.

Please cite this article in press as: Manoharan, T., et al. Engineering properties of concrete with partial utilization of used foundry sand. Waste Management (2017), https://doi.org/10.1016/j.wasman.2017.10.022

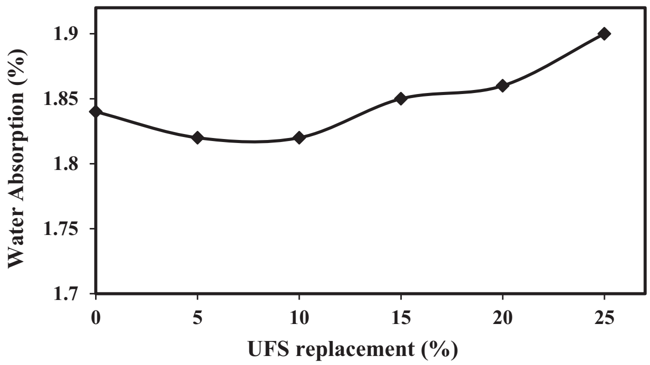

Fig. 7. UFS replacement Vs Water absorption.

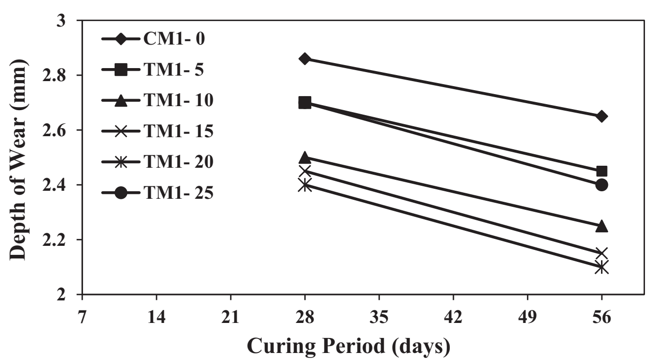

Fig. 8. UFS replacement Vs Depth of wear.

water absorption was practical. It could be probably due to the packing behavior between the particles. When the replacement goes beyond 10 wt% No more fine particles required for filling the voids between the particles.

3.2.2.4. Abrasion resistance. Abrasion resistance test results of 28 and 56 day cured M20 concrete with varying percentages of replaced UFS is shown in Fig. 8. The 28 day results of the control (0 wt% UFS) and trial mixture (20 wt% UFS) were 2.86 and 2.4 mm respectively. From these results, it was found that the depth of wear decreased with increase in curing time for all mixtures. Abrasion resistance of concrete increases with increase in UFS up to 20 wt%. Increase in abrasion resistance could probably due to increase in density of concrete. The improved density could be due to fine particles found in UFS.

3.2.3. Micro-structural properties

3.2.3.1. XRD studies. The XRD analysis of the control mix and the trial mix were shown in Figs. 9a and 9b. The primary and secondary peaks of C—S—H gel and SiO_2 were observed at 25°, 28° and 46°, 49° 2θ respectively. The formations of secondary peak intensities in control were less when compare to trial mix. It was evident that the inclusion of UFS promotes the formation of secondary peaks, when the replacement increases the peak intensity of SiO_2 improves. The intensity of silica in primary peaks was increased from 2000 to 2500 counts s^{-1} and formation of new secondary peak at 46° and 49° 2θ was observed for TM20. The excess SiO_2 decelerates the gel formation process and remains as insoluble residues. This excess amount of SiO_2 with respect to calcium content results in decrease of strength of concrete with increase in UFS after 20 wt%.

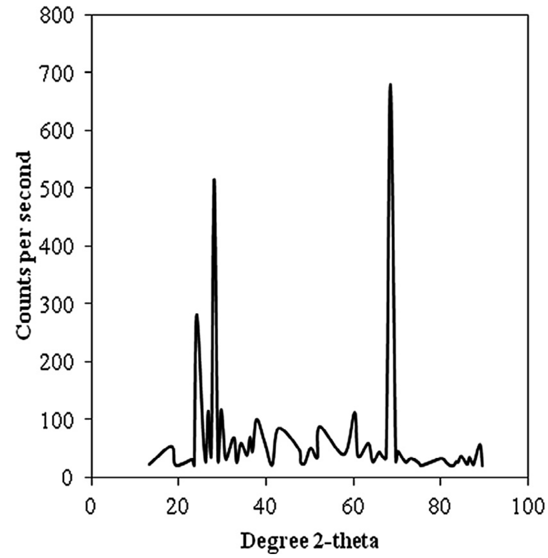

Fig. 9a. XRD image CM1-0 Sample.

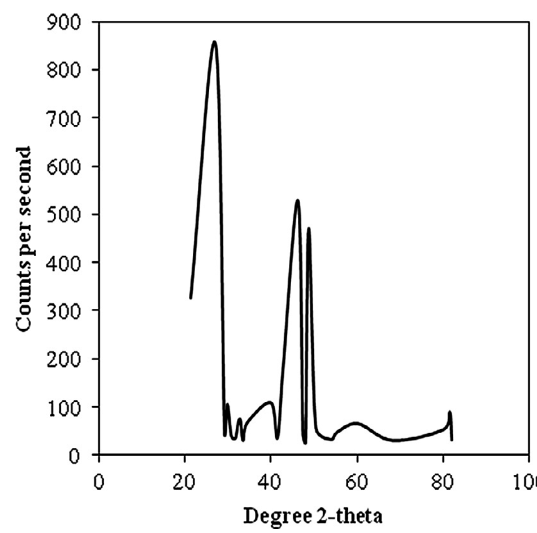

Fig. 9b. XRD image of TM1-20 sample.

3.2.3.2. SEM and EDX studies. SEM images were used for examining surface texture and crystal morphology where as EDX results were used to find the chemical composition. The images of control and trial mix were shown in Figs. 10a and 10b. The percentage of silica content in river sand and UFS were 35.7 and 55.6 wt% respectively. From the figure, it was observed that more amount of SiO_2 content promote the well-formed crystals as flowery like morphology due to eliminating or filling the voids (Hewlett, 2001; Yazici, 2007). While comparing to control mix the formation of C—S—H gels was optimum in TM20. This microstructure contributes to the densification of interfacial transition zone and lesser porosity up to 20 wt% of UFS, which helps to improve the mechanical and durability properties of concrete. When the UFS was increased the surface shows a visible difference. The reduction was observed in physical strength because of existence of excess of the fine particles and insoluble residues.

3.2.3.3. Optical microscope image analyses. The optical microscope images of control (CM1-0) and trial mix (TM1-20) were shown in Figs. 11a and 11b. These results describe the improvement in

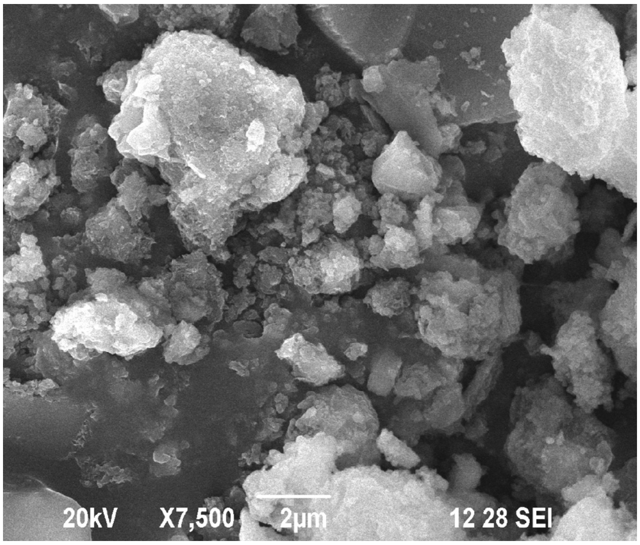

Fig. 10a. SEM image of CM1-0 sample.

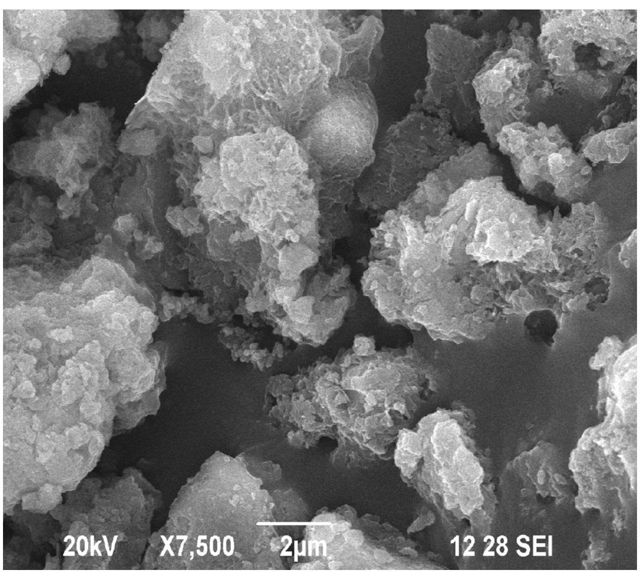

Fig. 10b. SEM image of TM1-20 sample.

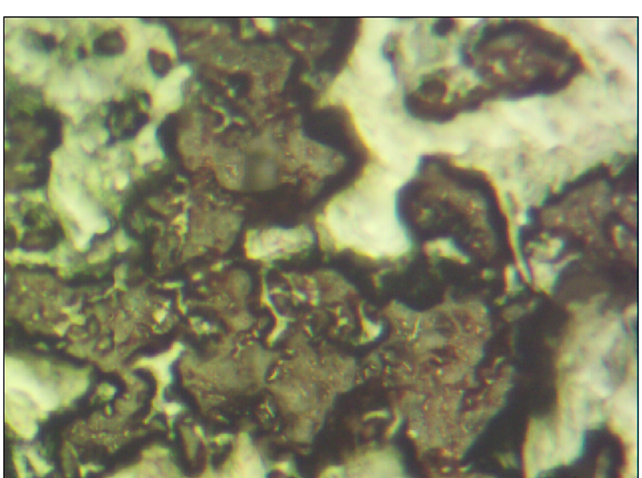

Fig. 11a. Optical microscope image of CM1-0.

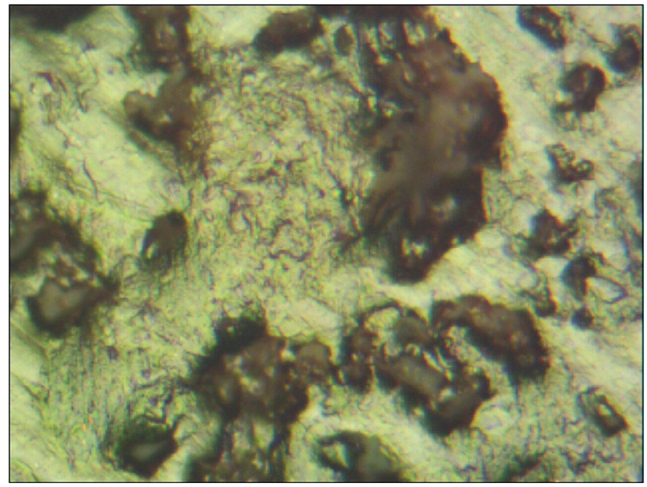

Fig. 11b. Optical microscope image of TM1-20.

compactness of microstructure, but reduction in the strength of concrete was observed beyond 20 wt%. This was because of poor binding of fine particles. These results were confirmed by XRD and SEM findings.

4. Conclusion

The present work investigated the influence of UFS as a partial replacement of fine aggregate in the production of concrete. On the basis of the test results the following conclusions are drawn.

1. Compressive strength, splitting-tensile strength, flexural strength and modulus of elasticity of concrete mixtures increased with the increase in replacement of UFS up to 20 wt%.
2. Concrete mixes having UFS above 20 wt% showed higher durability properties like ultra sonic pulse velocity, rapid chloride penetration, water absorption and abrasion resistance than that of concrete mixes without the replacement.
3. The mechanical, durability and micro structural properties test results obtain with 20 wt% replacement of UFS were comparatively higher than the other mixes.
4. Experimental results shown that the UFS can be effectively utilized for replacing river sand in concrete without affecting the concrete properties.

References

Amritkar, S.S., Chandak, S.N., Patil, S.S., Jadhav, R.A., 2015. Effect of waste foundry sand (WFS) on the mechanical properties of concrete with artificial sand as fine aggregate. Int. J. Eng. Res. Technol. 4, 390–393.

Neramitkornburi, A., Horpibulsuk, S., Shen, S.L., Chinkulkijniwat, A., Arulrajah, A., Disfani, M.M., 2015. Durability against wetting-drying cycles of sustainable lightweight cellular cemented construction material comprising clay and fly ash wastes. Constr. Build. Mater. 77, 41–49.

Arulrajah, A., Yaghoubi, E., Imteaz, M., Horpibulsuk, S., 2017. Recycled waste foundry sand as a sustainable subgrade fill and pipe-bedding construction material: engineering and environmental evaluation. Sust. Citi. Soc. 28, 343–349.

Arulrajah, A., Disfani, M.M., Maghoolpilehrood, F., Horpibulsuk, S., Udonchai, A., Imteaz, M., Du, Y., 2015. Engineering and environmental properties of foamed recycled glass as a lightweight engineering material. J. Clean. Prod. 94, 369–375.

Phetchuay, C., Horpibulsuk, S., Suksiripattanapong, C., Chinkulkijniwat, A., Arulrajah, A., Disfani, M.M., 2014. Calcium carbide residue: alkaline activator for clay-fly ash geopolymer. Constr. Build. Mater. 69, 285–294.

Bahoria, B.V., Parbat, D.K., Naganaik, P.B., Waghe, U.P., 2013. Comprehensive literature review on use of waste product in concrete. Int. J. Appl. Innov. Eng. Mgmt. 2, 387–394.

Hewlett, P.C., 2001. Lea's Chemistry of Cement and Concrete. Jordan Hill, Oxford.

IS: 10262-1982. Recommended guidelines for concrete mix design. Bureau of Indian standards. New Delhi, India.

IS: 1199-1959. Methods of sampling and analysis of concrete. Bureau of Indian Standards. New Delhi, India.
IS: 383-1970. Specification for coarse and fine aggregates from natural sources for concrete. Bureau of Indian standards. New Delhi, India.
IS: 516-1959. Methods of tests for Strength of concrete. Bureau of Indian Standards. New Delhi, India.
IS: 8112-1989. Scheme of testing and inspection for certification of 43 grade ordinary Portland cement. Bureau of Indian Standards. New Delhi, India.
Rahman, M.A., Imteaz, M., Arulrajah, A., Disfani, M.M., 2015. Suitability of recycled construction and demolition aggregates as alternative pipe backfilling materials. J. Clean. Prod. 66, 75–84.
Md, S., Wahab, A., Md, A.K., 2013. A study on the mechanical properties of concrete by replacing sand with waste foundry sand. Int. J. Emerg. Technol. Adv. Eng. 3, 83–88.
Prabhu, G.G., Bang, J.W., Lee, B.J., Hyun, J.H., Kim, Y.Y., 2015. Mechanical and durability properties of concrete made with used foundry sand as fine aggregate. Adv. Mater. Sci. Eng. 1, 1–11.
Saraswati, C.P., Jaykrushna, K.R., Palas, A.S., Jay, G.M., Ankit, N.P., 2013. Application of waste foundry sand for evolution of low cost concrete. Int. J. Eng. Trends. Technol. 4, 4281–4286.
Siddique, R., Schutter, G.D., Noumowe, A., 2009. Effect of used-foundry sand on the mechanical properties of concrete. Constr. Build. Mater. 23, 976–980.
Siddique, R., Singh, G., Belarbi, R., Mokhtar, K.A., Kunal, 2015. Comparative investigation on the influence of spent foundry sand as partial replacement of fine aggregates on the properties of two grades of concrete. Constr. Build. Mater. 83, 216–222.
Singh, G., Siddique, R., 2012a. Abrasion resistance and strength properties of concrete containing waste foundry sand. Constr. Build. Mater. 28, 421–426.
Singh, G., Siddique, R., 2012b. Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete. Constr. Build. Mater. 26, 416–422.
Yazici, H., 2007. Utilization of coal combustion byproducts in building blocks. Fuel. 86, 929–937.

Please cite this article in press as: Manoharan, T., et al. Engineering properties of concrete with partial utilization of used foundry sand. Waste Management (2017), https://doi.org/10.1016/j.wasman.2017.10.022