Development of Ternary Concrete Utilizing Agricultural Waste Material

Sunita Kumari (✉ sunitakumari.civil@dcrustm.org)  
DCRUST: Deenbandhu Chhotu Ram University of Science and Technology

Dhirendra Singhal  
Deenbandhu Chhotu Ram University of Science and Technology

Rinku Walia  
IKGPTU: IK Gujral Punjab Technical University Jalandhar

Ajay Rathee  
Deenbandhu Chhotu Ram University of Science and Technology

Research Article

Keywords: Ternary concrete, Scanning electron microscopy, Energy dispersive spectroscopy, Rice husk ash, Maize cob ash, X-ray diffraction

Posted Date: January 5th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1107515/v1

License: ☒ ☀ This work is licensed under a Creative Commons Attribution 4.0 International License.  
Read Full License
Abstract

The present project proposes to utilize rice husk and maize cob husk ash in the cement to mitigate the adverse impact of cement on environment and to enhance the disposal of waste in a sustainable manner. Ternary concrete / MR concrete was prepared by using rice husk and maize cob ash with cement. For the present project, five concrete mixes MR-0 (Control mix), MR-1 (Rice husk ash 10% and MR-2.5%), MR-2 (Rice husk ash 10% and MR-5%), MR-3 (Rice husk ash 10% and MR-2.5%), MR-4 (Rice husk ash 10% and MR-2.5%) were prepared. M35 concrete mix was designed as per IS 10262:2009 for low slump values 0-25mm. The purpose is to find the optimum replacement level of cement in M35 grade ternary concrete for I – Shaped paver blocks.

In order to study the effects of these additions, micro-structural and structural properties test of concretes have been conducted. The crystalline properties of control mix and modified concrete are analyzed by Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and X-Ray Diffraction (XRD). The results indicated that 10% Rice husk ash and 5% maize cob ash replaced with cement produce a desirable quality of ternary concrete mix having good compressive strength. The results of SEM analysis indicated that the morphology of both concrete were different, showing porous structure at 7 days age and become unsymmetrical with the addition of ashes. After 28 day age, the control mix contained more quantity of ettringite and became denser than ternary concrete. XRD analysis revealed the presence of portlandite in large quantity in controlled mix concrete while MR concrete had the partially hydrated particle of alite.

1 Introduction

Ordinary Portland cement acts as a binder in concrete and is important building material for the construction of infrastructure. In 2019, global cement consumption has increased up to 2.9%, reaching nearly 10 billion tons per year, and responsible for 7% of the emission of carbon dioxide in the atmosphere. Production of one-ton cement releases 0.8 tons of carbon dioxide and responsible for 5% emission of global emission. The rise in carbon dioxide concentration has created a greenhouse effect and increased the atmospheric temperature on the earth. The dry manufacturing process of cement consumes 723 Kcal/kg of clinker and 82kWh/ tonne cement of thermal and electrical energy, PM emission 303kg/ tonne of clinker without APCD, NOx emission 3.1 – 5.8 kg/tonne of clinker, SOx emission 4.9kg/tonne of clinker, CO₂ during calcination 0.57t – 0.63t, fuel combustion – 0.46 – 0.57t, etc. Therefore, cement manufacturing is not only responsible for CO₂ emission but gradually the depletion of fuel, energy, and natural resources of limited stocks. The requirement of sustainable development of binding material in the construction industry is the main issue to rectify the adverse impacts of cement manufacturing in the environment. To reduce demands and dependency on cement, emission of carbon dioxide, and other environmental problems, industrial and agro-waste by-products such as fly ash, granulated furnace slag, and rice husk ash (RHA) have been used as a substitute for cementitious materials [Kunal et al 2004, Karim et a.l 2014, Kunther et al. 2017 and Safiuddin et al. 2010].
RHA is produced by the combustion of rice husk, which is extracted portion of paddy during de-husking operation. The husk production rate of paddy rice is 20-25% while the ash production rate is 25% when burnt in the boilers. Organic compounds evaporate during combustion in the form of CO and silica remains as residue [Xu et al. 2016]. Kumar et al. (2012), concluded that the same can be used as fuel in the brick kiln, in the furnace and thermal power plant, and can produce 1MWh energy. Rao et al. (2014) and Zareei et al. (2017) found the specific gravity of RHA varied from 2.06 to 2.3 depending upon the topography and geographic parameters and having pozzolanic properties. Mehta (1994) observed that the mesopores of RHA particles absorbed free water and allowed calcium ion to diffuse into internal parts which further enhanced the pozzolanic capacity of rice husk shell in concrete. While Zareei et al. (2017) found 20% increment in compressive strength with a 15% replacement of RHA, Habbeb et al. (2010) observed 30.8% enhanced compressive strength of the concrete with 10% replacement.

Asonja et al. (2017) and Kyauta et al. (2015) suggested maize cob could also be used as fuel in power plant and 100g produce 600°C temperature depending upon the moisture content in it. Kamau et al. (2016) reported 25% silica content in corn cob ash and observed 20% enhanced compressive strength in concrete at 25% replacement levels.

Literature cite above corroborated the fact that the rice husk and maize cob can be used for the replacement of cement. The present project proposes to utilize rice husk and maize cob husk ash in the cement to mitigate the adverse impact of cement on environment and to enhance the disposal of waste in a sustainable manner.

2 Hydration Mechanism Of Rha And Mca

During the primary hydration reaction of cement, anhydrous calcium silicates react with water and produce CSH gel and calcium hydroxide (Ca(OH)\textsubscript{2}). Calcium hydroxide, which further reacts with amorphous silica present in RHA and MCA in secondary hydration reaction and produces a type of CSH gel. The primary and secondary reactions are given below by Siddique et al. (2018):

Primary hydration reaction of C\textsubscript{3}S and C\textsubscript{2}S with water

\begin{align*}
2(3\text{CaO}.\text{SiO}_2) + 6\text{H}_2\text{O} & \longrightarrow 3\text{CaO}.2\text{SiO}_2.3\text{H}_2\text{O} + 3\text{Ca(OH)}_2 (1) \\
2(2\text{CaO}.\text{SiO}_2) + 4\text{H}_2\text{O} & \longrightarrow 3\text{CaO}.2\text{SiO}_2.3\text{H}_2\text{O} + 3\text{Ca(OH)}_2 (2)
\end{align*}

Secondary hydration reaction

\begin{align*}
2\text{SiO}_2 + 3\text{Ca(OH)}_2 + \text{H}_2\text{O} & \longrightarrow 2\text{Ca}_{1.5}\text{SiO}_{3.5}.2\text{H}_2\text{O} (3)
\end{align*}

According to Boateng et al. (1990), Ca/Si ratio of CSH-1 produced from primary reaction and CSH-II gel produced from secondary may vary as shown below:

\begin{align*}
\text{CSH} – 1 = \text{CaO}_{0.8 - 1.5} \text{SiO}_2 (\text{H}_2\text{O})_{1.0 - 2.5} (4)
\end{align*}
CSH-II = CaO$_{1.5-2.0}$ SiO$_{2}$·2(H$_2$O) (5)

The initial Ca-Si ratio at the surface of the particles is near 3. As calcium ions dissolve out of this C–S–H gel, the Ca-Si ratio in the gel becomes 0.8-1.5. According to Garg (2016), Ca-Si ratio equals approximately 1.0 indicated the formation of tobermorite phase with similar to CSH, Ca-Si ratio less than 2.0 means formation of CSH gel, approximately equal to 2.0 indicated CSH gel formation with precipitated CH, and approximately 3.0 meant partially hydrated regions C$_3$A[Garg 2016].

The hydration products of Portland cement are responsible for the strength of concrete and the amorphous C-S-H phase with variable composition is expressed by its average Ca-Si ratio. The value of Ca-Si is approximately 1.75 in ordinary Portland cement whereas it decreases with increasing replacement with Supplementary cementitious materials. An increasing amount of C-S-H is formed as much as portlandite (Calcium hydroxide) present. After the depletion of the portlandite C-S-H amount is constant. The reduction in the Ca-Si ratio occurs as SiO$_2$ increases. The Ca-Si ratio on the C-S-H ranges from 0.67 – 2.0 with supplementary cementitious materials. Yang and Zhang (2012) explored that variation in Ca/Si ratio indicates the change in behaviors and microstructures of the concrete.

3 Materials And Methods

In this study, Ordinary Portland Cement 43 grade of Ultra Tech brand was used has 3.16 specific gravity and it confirmed the requirements of IS:8112 1989. The rice husk ash was collected from the rice mill near the area. The sum of main elements SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ was corresponding to 88.97% of rice husk ash chemical composition and fulfilled the requirements of ASTM 618C. Maize cob was collected from vendors and then converted into ash by burning at 1100°C temp. The ash obtained was crushed in a ball milling machine and from chemical analysis, the sum of these main compositions was found to be 33.35%. The chemical analysis and physical properties of Cement, RHA, and MCA have been shown in Table 1. The physical properties of fine and coarse aggregates confirmed the requirements of the IS:383 2016 and have been briefed in Tables 2 and 3.

| Chemical composition of OPC 43, RHA and MCA |
|---|---|---|---|---|---|---|---|
| OPC 43 | 20.58 | 4.98 | 3.89 | 57.21 | 0.15 | 1.27 | 2.54 | 0.57 | 4.0 |
| RHA | 85.48 | 3.04 | 0.45 | 2.36 | 0.08 | 0.56 | 0.75 | 1.7 | 5.5 |
| MCA | 28.02 | 4.39 | 0.94 | 2.75 | 0.15 | 1.02 | 1.48 | 5.03 | 34.45 |

Table 2. Properties of Coarse Aggregates
| Characteristics   | Value     |
|------------------|-----------|
| Color            | Reddish Grey |
| Shape            | Angular   |
| Maximum Size     | 20 mm     |
| Specific gravity | 2.75      |
| Water absorption | 1.33%     |
| Moisture content | 1.30%     |

**Table 3.**
Properties of Fine Aggregates

| Characteristics   | Range   |
|------------------|---------|
| Specific gravity | 2.80    |
| Water absorption | 0.60%   |
| Moisture content | 1.60%   |
| Sieve analysis   | Zone 2  |

### 3.1 Mix Design

M35 concrete mix was designed as per IS 10262:2009 for low slump values 0-25mm. The details of mix proportions are given in Table 4. Further, these mix proportions were also used to produce concrete with and without rice husk ash and maize cob ash. Cement was partially replaced with 10% of rice husk ash and maize cob ash is 2.5%, 5%, 7.5%, and 10% varying ratio. Five various concrete mixes MR-0 (Control mix), MR-1 (Rice husk ash 10% and MR-2.5%), MR-2 (Rice husk ash 10% and MR-5%), MR-3 (Rice husk ash 10% and MR-2.5%), MR-4 (Rice husk ash 10% and MR-2.5%) were prepared.

A ternary concrete mixture was used to mix well all the ingredients in all mixes. The raw materials were mixed for one minute until homogenous color appeared. Firstly 60% water was added to the dry mixer and then 40% of water added. The prepared concrete was placed in greased l-shaped paver blocks moulds of 200 mm x 120mm x100mm size. The samples were demoulded after 24 hrs. and cured for 7, 14,28, and 56 days. Three specimens for each curing age were conducted to determine the average compressive strength. After crushing the specimens for compressive strength, the crushed sample was collected and microstructure analysis FTIR, XRD, SEM, and EDS were performed. The XRD and SEM techniques were used to determine the crystal structure of the paver blocks concrete.
Table 4
Details of mix proportions for Mix design for 1m$^3$ of concrete.

| Concrete Mix (1 m$^3$) | Cement (kg) | Fine Agg. (kg) | Coarse Agg. (kg) | RHA (kg) | MCA (kg) | Water (kg) |
|------------------------|-------------|----------------|-----------------|----------|----------|------------|
| MR-0                   | 406.604     | 722.403        | 1208.072        | -        | -        | 174.840    |
| MR-1                   | 355.779     | 722.403        | 1208.072        | 40.660   | 10.165   | 174.840    |
| MR-2                   | 345.613     | 722.403        | 1208.072        | 40.660   | 20.330   | 174.840    |
| MR-3                   | 335.449     | 722.403        | 1208.072        | 40.660   | 30.495   | 174.840    |
| MR-4                   | 325.284     | 722.403        | 1208.072        | 40.660   | 40.660   | 174.840    |

4 Results And Discussions

4.1 Paver Blocks Compressive Strength

The compressive strength of 7, 14, 28, and 56 days control mix concrete and other mixes are shown in Figure 1. From Figure 1, the compressive strength of all mixes increased with the increase in curing age but it decreased with an increase in the amount of cement replacement with MCA. After MR-2, rice husk ash 10%, and Maize cob ash 5%, 28 days compressive strength was found to be less than 43MPa i.e., targeted strength. The control mix concrete (MR-0) had maximum strength as compared to other MR mixes. Large variation was observed between 7 and 28 days strength while minor increment was found afterward. This might be due to the presence of MCA, which had poor pozzolanic property as already discussed. According to Bapat. (2012) and Shetty (2005) the hydration reaction during the first 7 days did not involve MCA and it acted only as filler in concrete. Thereafter, SiO$_2$ present in ashes reacted with Ca(OH)$_2$ and formed CSH – II, and provided strength to the concrete. For MR-2 concrete, the 28 days compressive strength was found to be 44N/mm$^2$ which was greater than the target mean strength of 43.25 N/mm$^2$. Therefore, 10% RHA & 5% MCA was considered as optimum replacement level of cement in M35 grade ternary concrete for I − Shaped paver blocks.

4.2 Microstructural Analysis

4.2.1 FT-IR

Fourier – transformed infrared spectroscopy is used to obtain an infrared spectrum of absorption or emission of solid, liquid, or gas. It collects high – spectral- resolution data over a wide range. FT-IR is carried out on Perkin Elmer Frontier equipment using potassium bromide. The range is 4000 – 400 cm$^{-1}$ with 2 cm$^{-1}$ resolution. This study was carried out to correlate the curing age with the development of special features in FTIR spectra during the hardened concrete. Concrete cured in portable water for 7 day, 14 days, and 28 days and its wavenumbers and its functional groups of hydrated cement are given in Figures 2 and 3.
Control mix concrete

Silica absorption bands are found in the range of 500 – 700 cm⁻¹ due to the v₄ vibration of the SiO₄ group [Mollah et al 2004 and Ylmen et al. 2009]. The peak of SiO₄ rises with curing age and crystallize. Al-OH (800 – 850) cm⁻¹ OH bending stretch occurred and converted into an amorphous condition. The V₃ vibration of SiO₄⁴⁻ and SiO₄²⁻ are observed on 980 cm⁻¹ and (1100 – 1200 cm⁻¹) wavenumber, respectively. It converted into crystalline form with the hardening of concrete. The peak at v₁ vibration CO₃ at 1519 cm⁻¹ was formed due to carbonates, but it decreased at 28 days of hydration due to dilution of Ca⁺ ion and emission of CO₂. The CaCO₃ occurred at 2875 – 2879 cm⁻¹ and 2983 - 3010 cm⁻¹ wavenumber in vibration form due to calcium carbonate present in cement. The amount of calcium carbonate was observed to decrease due to the hydration reaction. The vibration of v₁ + v₃ vibration of H₂O and capillary water are formed at 3323 shifted to 3400 cm⁻¹ and a peak of 3450 cm⁻¹ wavenumber shifted to 3510 cm⁻¹ at 28 days of curing age. Peak of v₂ vibration of H₂O at the range of 1645 cm⁻¹ change into a broad peak from 7 days curing age to 28 days. Peak of v vibration of OH⁻ at the range of 3645 cm⁻¹ wavenumber also decreased with the curing age. The v₂ vibration of CO₃²⁻, v₁ symmetric stretching and v₃ asymmetric stretching CO₃²⁻ were observed at 850 cm⁻¹, 1070 cm⁻¹, and 1550 cm⁻¹ wavenumbers, respectively. The stretching of OH was present in a range of more than 3000 cm⁻¹ wavenumber. The peak of CaCO₃ stretching was at the range of 2358 cm⁻¹ wavenumber and it increased with curing age as also observed by Lee and Deventer 2002.

MR Concrete

By adding rice husk ash and maize cob ash, the sharp lower peak of SiO₄⁴⁻ was in a range of 535 cm⁻¹ wavenumber. The V₄ vibration and peak of SiO₄⁻ was at the range of 656 and 670 cm⁻¹ wavenumber on 7 days and converts into stretching band and broad peak after 28 days of curing. The small peak of Al-O and Al-OH at the range of 848 cm⁻¹ wavenumber was converted into a low stretching band on 28 days of curing. The stretch of SiO₄²⁻ had a weak shoulder at 1105 cm⁻¹ wavenumber. Carbonate (CO₃²⁻) stretch was at the range of 1400 – 1500 cm⁻¹ wavenumber with a smaller and flatter peak and shifted to more than 1500 cm⁻¹ wavenumbers as has also been confirmed earlier [Lee and Deventer 2002]. This shift indicated the change in hydration products. While the sharp, strong peak and spiral of CaCO₃ at the range of 2875 – 3000 cm⁻¹ wavenumber was converted into a small peak within 7 and 14 days but was sharper at 28 age curing age. When compared with controller concrete, it becomes obvious that hydration even at 28 days was not complete in presence of RHA and MCA. Vibration of v₂ of water in sulphate was present at the range of 1600 – 1650 cm⁻¹. The v₁ + v₃ vibration of H₂O, v₃ of H₂O, and capillary water and v₃ vibration of H₂O in gypsum was shown in the range between 3325 to 3600 cm⁻¹ wavenumber. These types of H₂O groups reduced with the time period. The peak of Ca(OH)₂ presents a range of 3650 cm⁻¹ was the wavenumber. Ca(OH)₂ is present in CSH at this range. Maximum changes are found between
3000 to 4000 cm⁻¹ where calcium hydroxide, gypsum, and capillary water decreased most probably with the pozzolanic reaction.

**Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD)**

A scanning electron microscope is a tool to study the microstructure of concrete. The experiment was performed by a low vacuum SEM model JOEL JSM – LV/100 with an energy dispersive X-ray (EDS) detector. The splinted piece of concrete was fixed in a sample holder with a carbon-coated with electrically conductive platinum material tape attached to the sampler in the machine. The study was conducted at 7, and 28 days of curing age for both controlled concrete and MR specimens.

The X-ray diffraction test was used to establish the hydration peaks that appeared in the concrete at 7 and 28 days curing age. The collected samples were dipped in anhydrous ethanol to block the further hydration in concrete. The broken concrete pieces were grounded to a size fewer than 75 microns to use for XRD analysis. The mineralogy was studied with monochromatic Cu - Kα radiation at a scattering speed of 1.5° (2θ) min⁻¹. The powdered samples were affixed to the sampler and the top surface of the sample was streaked by a glass slide to obtain a uniform surface. The samples were placed in the diffractometer and scanned in continuous mode from 10° – 80° with a scanning rate of 0.05°/ Sec.

**Concrete at 7 days of curing period**

Figure 4 shows the SEM image after 7 days of hydration of control mix concrete. During the hydration reaction, it has produced glossy quartz (SiO₂) low in quantity. White precipitation over particles of portlandite (CH) and CSH like cotton was observed in abundance around the anhydrous particle. In Figure 5, EDS of microstructure analysis shows that the whitened area consists of the average Ca/Si ratio of 2.03 confirming the formation of portlandite. XRD analysis showed the minerals present and their contribution to the increase in strength and development of concrete. 1- Quartz low, 2 – Portlandite, and 3 – Sinnerite in XRD analysis. Since the age of concrete was 7 days, many voids could also be seen. The compressive strength of concrete is found to be 30.50 N/mm².

Figure 6 (a) shows the SEM image of 7days Maize cob and Rice Husk Concrete. By adding rice husk and maize cob ashes in concrete, hydration reaction produced, the round dark porous structure, needles of silica (Quartz), and bright parts of anhydrous alite (Ca₃O₅Si) which covered more than 50% of the visible area. Figure 6(b) The XRD analysis showed that peaks of alite were very less and were in an amorphous state. 1- Quartz low, 2 - Alite (Ca₃O₅Si), 3 – As₈ Cu₁₂S₁₈ in XRD analysis. The presence of calcium hydroxide is less quantum when compared with control mix concrete indicated the slow rate of hydration process of MR concrete due to a large amount of silica in ashes and pozzolanic reaction. Black spherical particles both hollow and solid of ashes were also clearly observed. Many voids at this age of 7 days as were in controlled concrete could also be observed. The 7 days compressive strength is found at 20.2 N/mm². Figure 7, EDS analysis found Ca/Si ratio is 1.8 which was less than 2 indicated the formation of CSH gel.
Concrete at 28 days of curing period

Figures 8 (a) & (b) and 9 show SEM analysis, XRD and EDS analysis of 28 days control mix concrete. When compared with Fig 4, this figure confirms the concrete has now hydrated, the voids were less and CSH particles along with ettringite needles were observed. EDS analysis found that Ca/Si was more than 1.5 which indicated the formation of CSH in crystal form. XRD analysis shows the peaks of quartz become lower and Ca(OH)$_2$ getting higher. Peaks of sinnerite become prominent as compared with 7 days control mix concrete. 28 days compressive strength enhanced up to 45.40N/mm$^2$.

Figure 10(a) & (b) and 11 show the SEM, XRD and EDS analysis of 28 days MR concrete. SEM image showed that concrete had hydrated, contained quartz in bright portion and very less amount of alite. It became dense and fewer needle-like ettringite crystals were produced as compared to 7 days MR concrete. EDS analysis revealed that Ca/Si ratio is 1.3 indicating the formation of CSH crystal. It was found that the Ca/Si get decreased by adding SCM in concrete as also observed earlier by Ahmadi (2016). XRD curve indicated reduced quantity of that alite. The quantum of CH was also much less as compared with controlled concrete which is main susceptible from the aspect of durability. The 28 days compressive strength is found to be 44 N/mm$^2$.

5 Conclusions

Based on the above results and analysis presented following conclusions can be drawn:

- The results show that the compressive strength of concrete increases with decreasing the Ca/Si ratio. The Ca/Si ratio of control mix concrete varies from is 2.03 to 1.5 while for MR concrete 1.8 to 1.3 in 7 and 28 days respectively.
- Based on 28 day compressive strength, 10% RHA & 5% MCA was considered as optimum replacement level of cement in M35 grade concrete for I – Shaped paver blocks.
- The morphology of both types of concrete is very different and XRD analysis shows the presence of portlandite in large quantity in control mix concrete while MR concrete has the partially hydrated particle of alite.
- The results of FTIR analysis have indicated the presence of carbonates and partly depolimerised C-S-H gel in all samples in comparison to the control sample.

Declarations

CONFLICT OF INTEREST: On behalf of all authors, corresponding author states that there is no conflict of interest.

ETHICS APPROVAL

Not applicable.
CONSENT FOR PUBLICATION

Not applicable.

CONSENT TO PARTICIPATE

Not applicable

AVAILABILITY OF DATA AND MATERIALS

The data analysed during the current study are available from the corresponding author on reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests the publication of this article.

ACKNOWLEDGMENT: We would like to thank Deenbandhu Chhotu Ram University of Science & Technology, Murthal, India for funds and facilities provided to accomplish this Minor Research Project

AUTHORS’ CONTRIBUTIONS

Sunita Kumari: Data curation, Conceptualization.

Dhirendra Singhal: supervision, validation

Rinku Walia: Writing, review and editing

Ajay: experimentation, Investigation.

References

1. Ahmadi R.(2016) et al. Production and Characterization of Microfine sized palm oil fuel ash (POFA) originated from bau, lundu palm oil mill. Hasan, A. et al. (eds.)Innovative Solutions for Engineering and Technology Challenges. 9th International conference Unimas Stem Engineering Conference (ENCON2016), Malaysia, October 2016, Lecture notes in Civil Engineering, Vol. 87, pp. 1-8. MATEC web of Conferences, Doi:10.1051/mateconf/20178701012

2. Asonja A, Desnica E, Radovanovic L(2017). Energy efficiency analysis of corn cob used as a fuel, energy sources, Energy Source, Part B: Economic Planning and Policy. 12(1): 1-7. doi.: 10.1080/15567249.2014.881931

3. Bapat JD (2012). Mineral Admixtures in Cement and Concrete. CRC press.

4. Boateng AA, Skeete DA (1990). Incineration of rice hull for use as a cementitious materials: the guyana experience. Cem. and Concr. Res., 20(5): 795 – 802. doi.:10.1016/0008-8846(90)90013-N
5. Garg R(2016). Mechanical, durability & microstructure aspect of cement mortar incorporating micro & nano silica. Dissertation, GZSCET Punjab Technical University.

6. Habeeb GH, Mahmud H B(2010). Study on properties of rice husk ash and its uses as cement replacement materials. Mat. Res. 13 (2): 185 – 190. doi.: 10.1590/S1516-14392010000200011

7. Kamau, J., Ahmed, A., Hirst, P., Kangwa, J. Suitability of comcob ash as a suitability cementitious materials. Int. J. Mat. Sci. and Engg. 4(4), 216 – 228 (2016). doi.: 10.17706/ijmse.2016.4.215-228

8. Karim Md.R, Houssain Md M, Khan Md NN (2014). On the utilization of pozzolanic waste as an alternative resource of cement. Materials. 7: 7809 – 7827. doi.: 10.3390/ma7127809

9. Kumar A, Mohanata K, Kumar D, Parkash O(2012). Properties and industrial applications of rice husk: a review. Int. J. Emerg. Tech. and Adv.Engg. 2(10), 86-90.

10. Kunal, Siddique R., Razor A (2004) Influence of bacterial treated cement kiln dust on the properties of concrete. Const. and Build. Mater. 52: 42–51 . doi.:10.1061/(ASCE)MT.1943-5533.0001593

11. Kunther W, Ferreiro S, Skibsted J(2017). Influence of Ca/Si ratio on the compressive strength of cementitious calcium – silicate binders. J. Mater. Chem. A. 5: 17401 – 17412. doi.:10.1039/C7TA06104H

12. Kyauta E E, Adisa AB, Abdulkardir LN, Balogun S(2015). Production and comparative study of pellets from maize cob and groundnut shell as fuel for domestic use. Ameri. J.Engg. Res. 4(1): 97 – 102 (2015).

13. Lee WKW, Deventer JSJ(2002): The effects of inorganic salt contamination on the strength and durability of geopolymers. Coll. Surf A: Physio. and Engg. Aspect. 211:115 -126 . Doi:10.1016/S0927-7757(02)00239-X

14. Lin RS, Wang XY, Lee HS, Cho HK (2019). Hydration and microstructure of cement paste with calcined hwangtoh clay. Materials. 12: 458 – 478. Doi.: 10.3390/ma12030458

15. Mehta, P.K. (ed.): Advances in Concrete Technology. CANMET, Ottawa (1994)

16. Mollah YA, Kesmez M, Cocke DL(2004). An x-ray diffraction (XRD) and fourier transform infrared spectroscopic (FT-IR) investigation of the long – term effect on the solidification/stabilization (S/S) of arsenic (V) in Portland Cement type -V. Sci. of the Total Envi. : 255 – 262 .

17. Rao P P, Kumar A P, Singh B B(2014). A study on use of rice husk ash in concrete. Int. J. Ed.App. Res. 4(2).

18. Safiuuddin Md, Jumaat Z, Salam MA, Islam Md S, Hasim R(2010). Utilization of solid waste in construction materials,. Int. J.Phys. Sci. 5(13): 1952 – 1963.

19. Shetty M.(2005). Concrete Technology: Theory and Practice. S. Chand. India

20. Siddique R., Cachim, P.(2018). Waste and Supplementary Cementitious Materials in Concrete, Woodhead Publishing, Cambridge, UK ..

21. Xu W, LoT Y, Wang W(2016). Pozzolanic reactivity of silica fume and ground rice husk ash as reactive silica in a cementitious system: A comparative study. Materials. 9: 146 – 160. doi.:10.3390/ma9030146
22. Yang T, Yao X, Zhang Z(2012). Mechanical property and structure of alkali – activated fly ash and slag blends. J. of Sust. Cement – Based Mat. 1(4): 167 – 178. Doi.: 10.1080/21650373.2012.752621

23. Ylmen R, Jaglid U, Steenari B.N et al. (2009). Early hydration and setting of portland cement monitored by IR, SEM, and vicat techniques. Cement and Con. Res. 39: 433 – 439. doi.:10.1016/j.cemconres.2009.01.017

24. Zareei SA, Ameri F, Dorostkar F, Ahmadi M.(2017). Rice Husk Ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties. Case studies in Const. Mat. 7: 73 – 81. doi.:10.1016/j.cscm.2017.05.001

Figures

Figure 1

Compressive strength of Concrete (MPa)

Figure 2

FTIR analysis of Control Mix Concrete

Figure 3

FTIR analysis of MR-2 Concrete
Figure 4

(a) & (b). SEM and XRD image of 7 days Control Mix Concrete

| Element | Weight % | Atomic % |
|---------|----------|----------|
| O       | 56.44    | 74.7     |
| Ca      | 26.66    | 14.08    |
| Si      | 9.22     | 6.95     |
| Al      | 1.88     | 1.47     |
| Fe      | 2.01     | 0.76     |
| K       | 1.06     | 0.58     |
| Mg      | 0.55     | 0.48     |
| Mo      | 1.29     | 0.28     |
| S       | 0.51     | 0.34     |
| Na      | 0.38     | 0.35     |

Figure 5

EDS analysis of 7 days Control mix Concrete

Figure 6

(a) & (b). SEM and XRD images of 7 days MR Concrete

| Element | Weight % | Atomic % |
|---------|----------|----------|
| C       | 43.18    | 54.66    |
| Ca      | 11.11    | 4.22     |
| Si      | 4.67     | 2.53     |
| O       | 40.30    | 38.30    |
Figure 7
EDS analysis of 7 days MR Concrete

Figure 8
(a) & (b). SEM and XRD image of 28 days Control mix Concrete

| Element | Weight % | Atomic % |
|---------|----------|----------|
| O       | 49.95    | 60.44    |
| Si      | 10.58    | 7.29     |
| Ca      | 25.31    | 12.23    |
| C       | 11.15    | 17.97    |
| Al      | 1.15     | 0.83     |
| S       | 0.61     | 0.37     |
| Mg      | 0.79     | 0.63     |
| Cl      | 0.46     | 0.25     |

Figure 9
EDS analysis of 28 days MR concrete

Figure 10
SEM and XRD image of 28 days MR concrete
Figure 11

EDS image of 28 days MR concrete

| Element | Weight % | Atomic % |
|---------|----------|----------|
| O       | 58.47    | 67.88    |
| Ca      | 17.42    | 8.07     |
| Si      | 9.22     | 6.1      |
| Fe      | 1.33     | 0.44     |
| Al      | 1.53     | 1.06     |
| C       | 9.79     | 15.14    |
| K       | 0.93     | 0.44     |
| Mg      | 0.62     | 0.47     |
| S       | 0.68     | 0.39     |