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Microstructural Analysis of Recycled Brick Aggregate Concrete Exposed To High Temperatures

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ABSTRACT: *The aim of this investigation is to determine the physical, mineral and morphological properties of recycled brick aggregate at elevated temperatures.The two series of concrete mix i.e.normal aggregate concrete (NAC) and recycled brick aggregate concrete (RBAC) were prepared and subjected to temperatures between 100-800°C at intervals of 100°C for 3 hours of exposure. XRD and SEM analysis were done after exposing them to temperatures. From the compression test it is concluded that the fire resistance of recycled brick aggregate concrete is better than the normal aggregate concrete. This better performance of RBAC at high temperatures could be attributed to lower deterioration rate of C-S-H gel than NAC which can be perceived from SEM and XRD analysis.*
KEY WORDS: *Recycled brick aggregate, elevated Temperature, Compressive strength, SEM, EDX, XRD.*

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I. INTRODUCTION

Concrete is generally considered to have good fire resistance being incombustible, non-flammable, and does not release toxic fumes during and after fire. But, concrete subjected to high temperature (e.g., due to accidental fire etc.) leads to severe deterioration and it undergoes a number of transformations and reactions, thereby causing progressive breakdown of cement gel structure and consequent loss in its load-bearing capacity, reduced durability, increased tendency of drying shrinkage, structural cracking, and associated aggregate colour changes. Assessment of this deterioration of concrete composition is an important requirement to determine the possible corrective measures in rehabilitation.

Research is very limited on the fire resistance of concrete made with crushed clay brick aggregate or recycled masonry. Recycled brick aggregate in concrete changes the cement hydration process and also the chemical properties of concrete. X-Ray Diffraction (XRD) provides most definitive structural information including inter-atomic distances and bond angles.

Scanning Electron Microscopy (SEM) allows examination of micro structural details at a greater definition than an optical microscope. Due to its high resolution and analytic capabilities, SEM with image analysis provides several advantages in cement petrography.The X-ray microanalysis can be done in the selected spot for analyzing the constituents for its elemental composition.The main objective of this project is to study the XRD and SEM analysis of the recycled brick aggregate concrete subjected to elevated temperatures.

II. LITERATURE REVIEW

SedatKaraman et al (2006) [1]studied the firing time effect on compressive strength, water absorption, weight loss and clay mineralogy. It was observed that as the temperature increased the strength of the brick also increased to some extent. As the temperature increased the weight loss also increased as a result of loss of organic matter in clay.

QiongLui et al (2014)[2] investigated the use of hybrid recycled powder as a supplementary cementing material. The author noted that with the increase of clay brick, tests showed that the fineness and strength activity index rise up to 40% replacement, weaker ITZ, weaker bond of C–S–H gels. Based on the results, the author concluded that the activity mechanism of hybrid powder is strongly correlated with its unique microstructure morphology and chemical composition and if the proportion of clay brick was well designed, hybrid powder would have potential of being used as a cement supplement for concrete.

FatihBektas (2014) [3] investigated the alkali reactivity of crushed red clay brick aggregate based on laboratory findings using mortar mixes (10%, 25%, 50% and 100% replacement of aggregate), and concrete mixes (0%, 50% and 100% crushed coarse brick aggregate). The author conducted micro-structural investigation on samples using SEM-EDS with the results showing linear expansion of samples caused by clay brick aggregate and presence of alkali silica gel along with ettringite formation. According to the author, high alkali concrete mixes with brick aggregate demonstrated higher expansions compared to the control mix without affecting theengineering properties of concrete.

Gai-FeiPeng et al (2008) [4]studied the change in microstructure of hardened cement paste (HCP) caused due to elevated temperatures between 400 and 800°C. It was noted that exposure to elevated temperature had a significant coarsening effect on the pore-structure of HCP; hence the strength loss below 600°C was mainly caused by the pore-structure coarsening rather than C–S–H decomposition. The author concluded that it was only above 600°C that the decomposition became significant and the C–S–H decomposition rate increased dramatically with temperature.

S.K. Handoo et al (2002) [5] investigated the affect of elevated temperature on physico-chemical, mineralogical, and morphological characteristics of concrete. The author heated concrete cubes prepared from OPC of known properties, up to 1000°C in steps of 100°C for a period of 5 hours. The author noted that total deterioration of concrete occurred at 700°C at the surface and 900°C at the core due to decomposition of CH with the clear deformation of well-developed CH crystals and C-S-H gel beyond 600°C. The author concluded that with increase in temperature there was a decrease in the CH content which led to a consequent reduction of concrete strength.

III. MATERIALS

3.1 Cement: Ultratechportlandpozzolona cement with specific gravity 3.1 and fineness 345 m²/kg and 32.5% consistency was used in this investigation. The 28 days compressive strength of he cement was found to be 62.4 N/mm^2 which was confirming to the limits specified in IS 1489- 1991 [7].

3.2 Sand: The locally available river sand with specific gravity 2.56 and fineness modulus 2.76 confirming to zone II was used . The sieve analysis was carried out in accordance with IS 2386 (Part I) -1963 [8].

3.3 Coarse Aggregate: Thenaturally crushed granite aggregate of size 20 mm with specific gravity 2.72 and fineness modulus 7.10 is used in the investigation to compare with the crushed clay brick aggregate. The collected brick aggregate is crushed down to 20mm and 10 mm sizes manualy and coated with the cement slurry (1: 4 ratio) to reduce its water absorption. Both the granite aggregate and recycled brick aggregate are used in saturated surface dry (SSD) condition. The specific gravity and fineness modulus of recycled brick aggregate was found to be 2.20 and 7.06 respectively. These properties of both the aggregate are determined in accordance with IS 2386 (Part III) -1963 [8].

IV. EXPERIMENTAL INVESTIGATION

In this paper an attempt is made to study the microstructural properties fire affected recycled brick aggregate concrete and compared with the natural aggregate concrete. The concrete was prepared using the mix proportions 1:1.25:2.8 with water cement ratio of 0.52. The natural aggregate was replaced with recycled brick aggregate by 25% of its volume from the calculated mix proportions. The specimen of size 150 mm × 150 mm × 150 mm were cast, compacted and cured for 28 days with periodic water changing every 7 days.The cured cubes were air dried till complete loss of the moisture content on the surface and then exposed to the temperatures between 100 to 800^{o}C in Bogie Hearth furnace for the duration of three hours. These specimen are then tested for its compressive strength and microstructural properties by using XRD, EDX and SEM.

4.1. Scanning Electron Microscopy

The core section of the concrete cubes is cut out by removing the outer sections of the cubes. A small sample of size less than 10mm in dimensions is taken. The concrete specimen is first mounted on a metal using rapid drying glue. The sample taken must be conducting or at least semiconducting. If sample is not electrically conducting, it will require carbon or gold coating which is done by using Quorum-SC7620 Sputter Coater. The test is conducted using a ZEISS EVO Series Scanning Electron Microscope (EVO 18).

4.2. Powder X-Ray Diffraction

The core section of the concrete was extracted from the cubes of temperatures 27ºC, 600ºC, 700ºC, 800ºC. These samples were then powdered and sieved through 75µm. About 10gm-15gm of the sample was collected in an air-tight container to prevent moisture. These samples were then used for testing. For the XRD analysis, we use diffraction devices (diffractometers), mainly according to the Bragg - Brentano system (the sample rotates at a diffraction angle "θ", while the detector rotates at the angle "2θ".) The sample was placed on a sample holder. This sample holder was then placed in the diffractometer for testing using a PANalytical 3 kW X'pert Powder– Multifunctional XRD unit with a Cu LFF High Resolution X-ray tube.

V. RESULTS AND DISCUSSION

5.1 Compressive Strength Test

Figure 1 shows the variation of residual compressive strength between the natural aggregate concrete and recycled brick aggregate concrete after exposing to high temperatures. Both RBAC and GAC have exhibited rising to falling trend in residual compressive strength when exposed to temperature. Both the concretes exhibited higher residual strengths up to a temperature of 200ºC than that at room temperature. The increase in residual compressive strengths of both the concretes may be due to the accelerated hydration.

Both the concretes demonstrated a dramatic fall in residual compressive strength between 200 and 300ºC. At 300ºC both the concretes retained almost same residual strength. Gradual decrease in residual compressive strength was recorded beyond 300ºC. However the RBAC could able to retain more residual compressive strength than GAC at every temperature beyond 300ºC. The RBAC depicted a strength gain in the range between 9 to 16.25% between 400ºC to 1000ºC. It can be concluded that the RBAC performed well than GAC at every temperature by retaining either the same or more strength. This enhanced performance may be attributed to the fact that clay in the brick becoming stiff and strong at high temperatures.

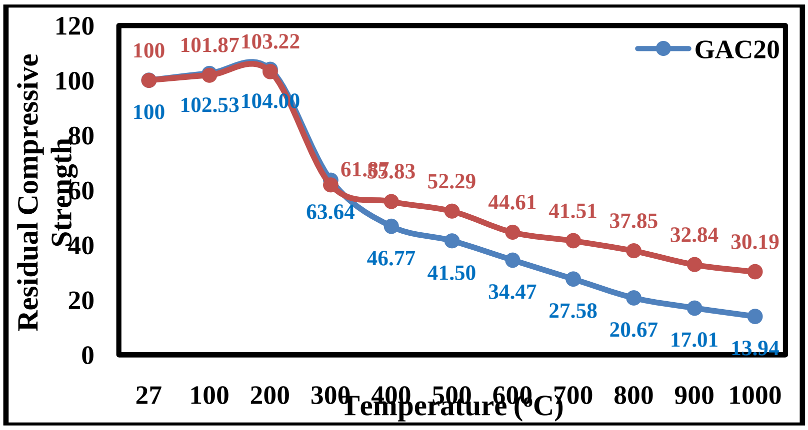

Figure 1: Variation of Residual Compressive Strength of NAC and RBAC

5.2 SEM with EDX studies

SEM studies on concrete show distinct changes in the morphology as a consequence of exposure to elevated temperatures. A number of micrographs displaying the effect of temperature on normal and recycled aggregate concrete are shown in Figures 2 to Figure 9. The SEM micrographs of NAC and RBAC at room temperature reveals a well-developed hydrated phases such as C-S-H gel intermixed with $Ca(OH)_2$ crystals (C-H) along with quartz and ettringite content. There is also a greater prevalence of voids and pores in RBAC compared to NAC at room temperatures.

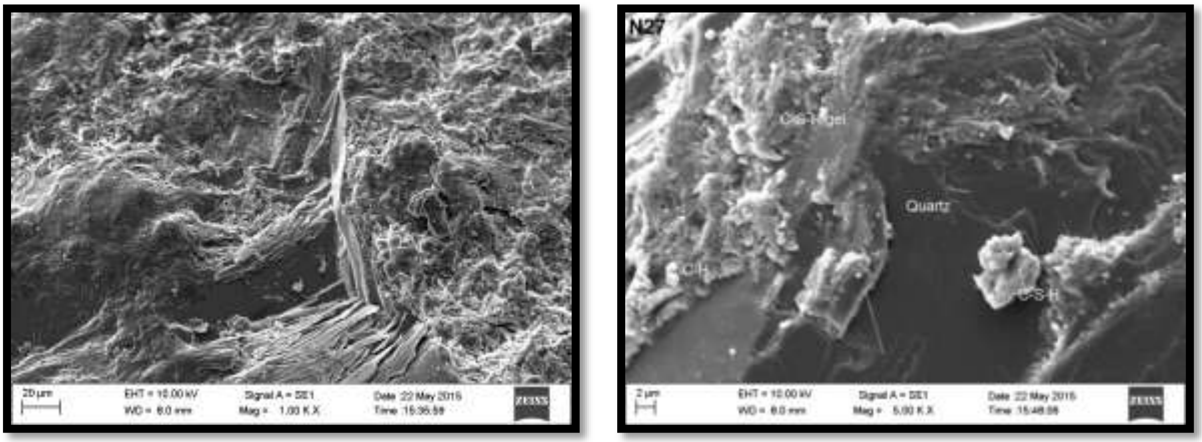

Figure 2:SEM images of NAC at room temperature

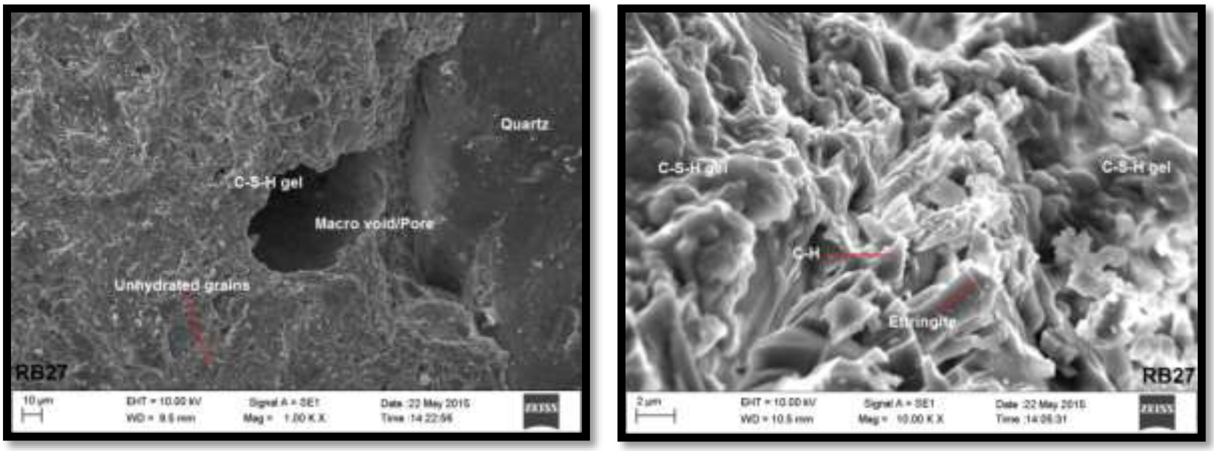

Figure 3: SEM images of RBAC at room temperature

SEM analysis of NAC and RBACat temperatures 600°C showed deformation of C-H crystals and C-S-H gel, and increase in voids in NAC. Further analysis at 700°C and 800°C indicated the increase in the formation of microcracks and voids due to increase in porosity, deteriorated $Ca(OH)_2$, and C-S-H gel. This increase in microcracks and voids was more predominant in NAC as compared to RBAC. There was evidence of partial vitrification of the brick aggregate in RBAC at higher temperatures as seen in Figure 8. The deterioration of C-S-H gel was more in case of NAC compared to RBAC at higher temperatures.

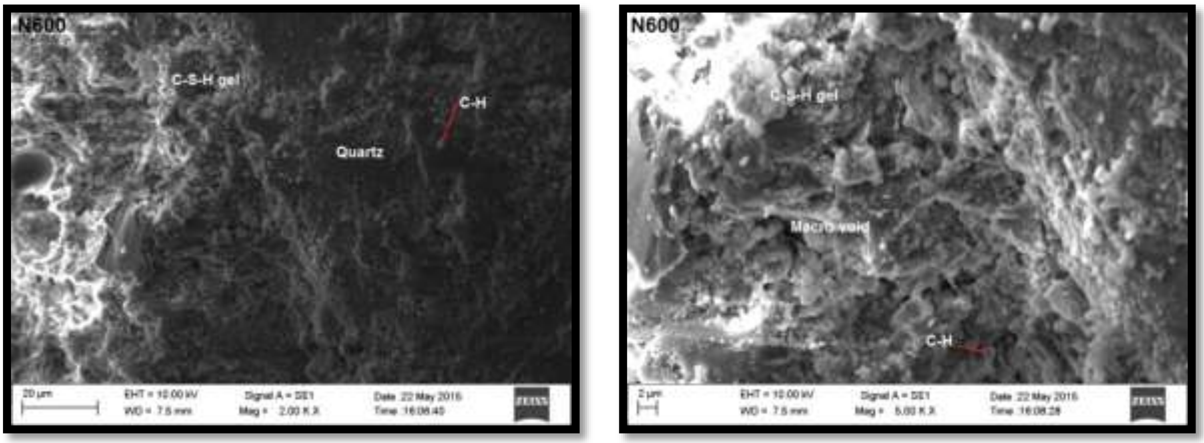

Figure 4:SEM images of NAC at 600^{o}C

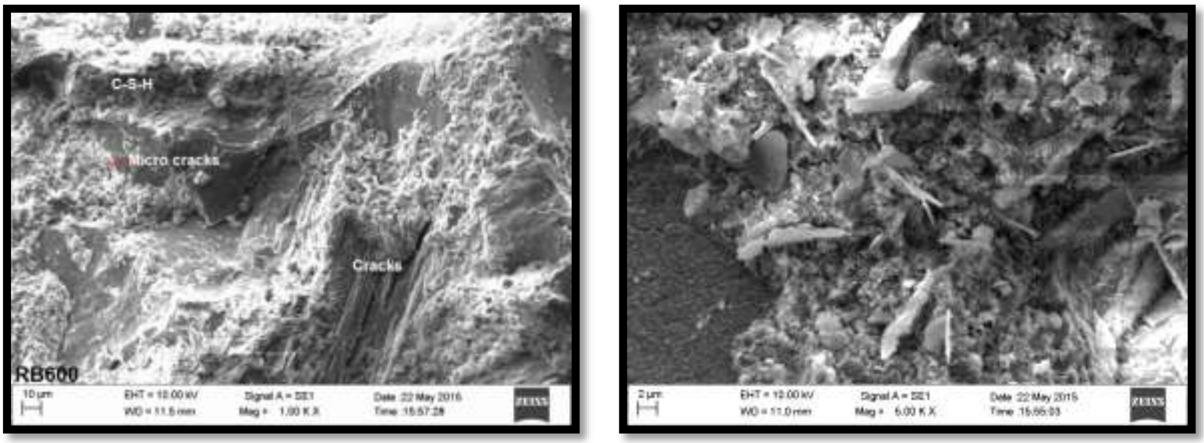

Figure 5: SEM images of RBAC at 600^{o}C

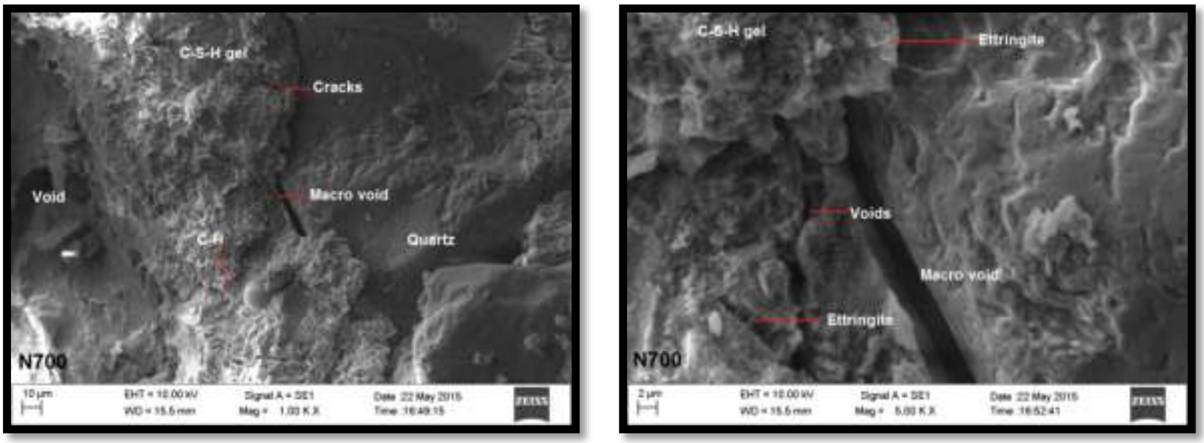

Figure 6:SEM images of NAC at 700°C

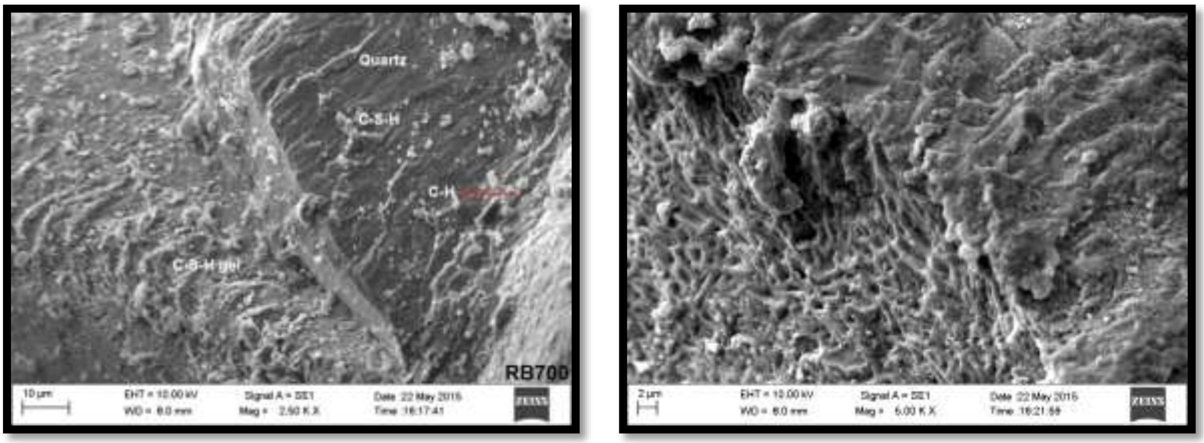

Figure 7: SEM images of RBAC at 700°C

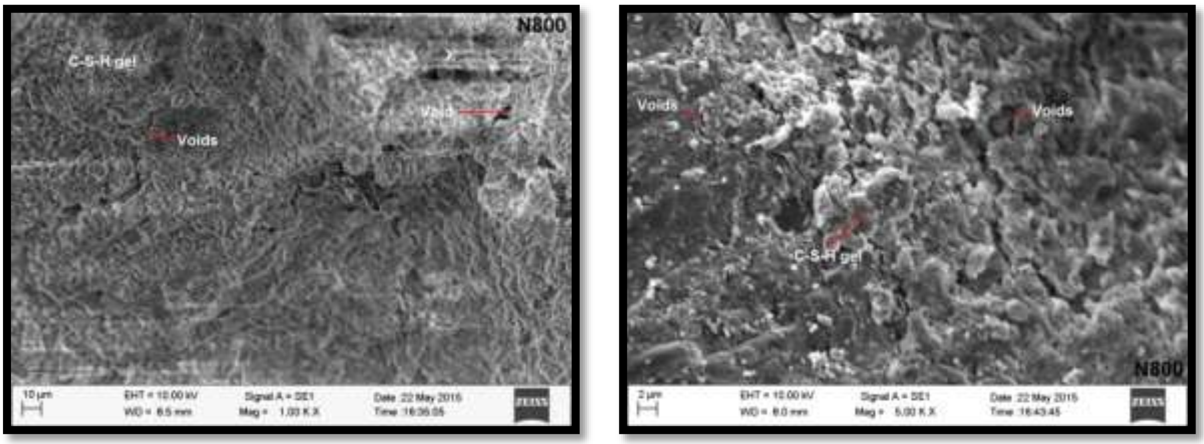

Figure 8:SEM images of NAC at 800°C

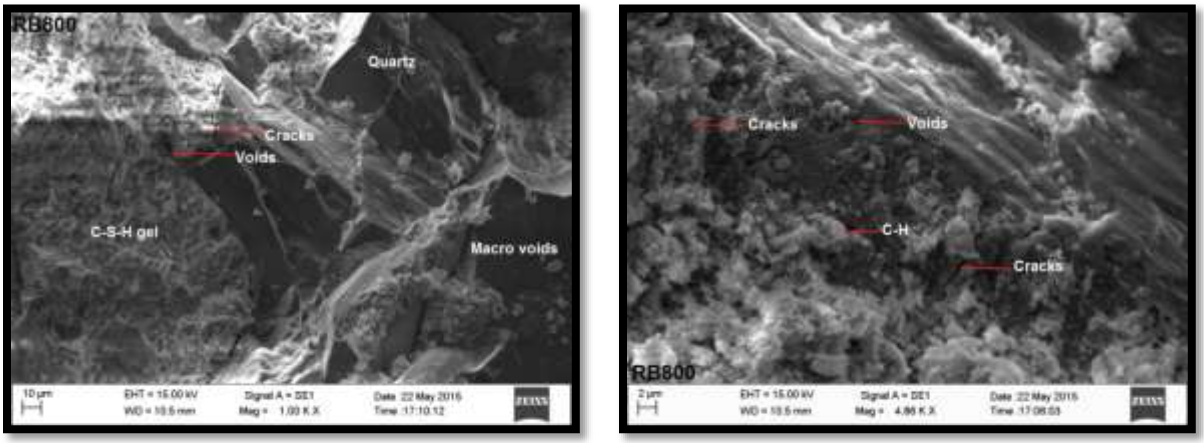

Figure 9: SEM images of RBAC at 800°C

5.3 Powder XRD Analysis

The XRD analysis of recycled brick aggregate concrete and normal aggregate concrete samples at room temperature and samples exposed to 600°C, 700°C and 800°C temperatures is done to determine the changes in these phases of concrete. The presence of usual hydrated phases such as Portlandite(C-H), Calcium Silicate Hydrate (C-S-H), Ettringite, Anorthite and Quartz can be seen in the Figures 10-11.

At room temperature, the quartz content of NAC compared to RBAC is slightly higher, which impacts the hardness of the normal concrete. At higher temperatures of 600°C, 700°C and 800°C quartz causes expansion cracks to form in the concrete due to internal stresses produced by the expansion of the aggregates. Hence, due to higher quartz content in the RBAC samples at elevated temperatures, expansion cracks are more which leads to lesser strength. The ettringite formation is more in NACas compared to RBAC under normal conditions and also at elevated temperatures. The ettringite formation after the completion of the hydration reaction grows into the gel structure and cause cracks to occur in the cement paste, this causes the strength to decrease. The C-S-H gel content is higher in RBAC at all temperatures compared to NAC. On the other hand, the portlandite phase is highest at room temperature and deteriorates at higher temperatures with minimal C-H phase seen at 700°C and 800°C for both NAC and RBAC. This occurs due to the breakdown of $Ca(OH)_2$ into CaO and H_2O. This CaO reacts with the silica content and forms secondary C-S-H gel.

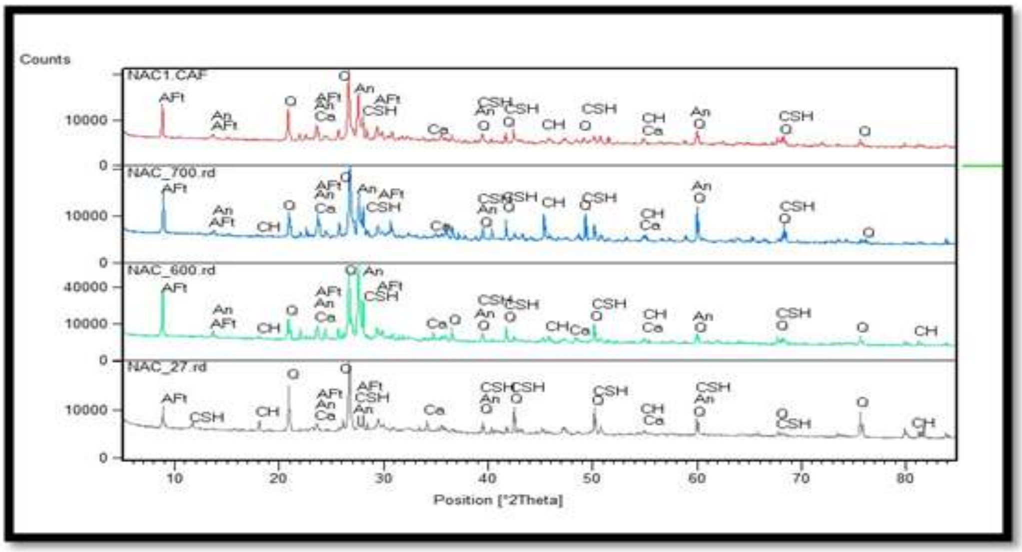

Figure 10: XRD graphs of Normal Aggregate Concrete at 27ºC, 600ºC, 700ºC and 800ºC

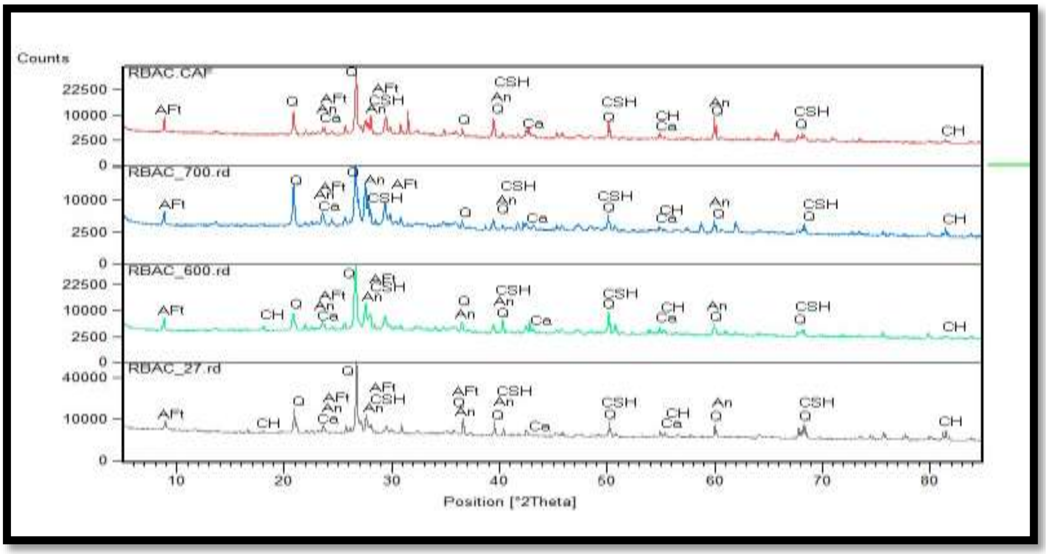

Figure 11: XRD graphs of Recycled Brick Aggregate Concrete at 27ºC, 600ºC, 700ºC and 800ºC

VI. CONCLUSIONS

1. RBAC performed well than GAC at every temperature by retaining either the same or more strength.
2. SEM analysis of NAC and RBAC specimens shows the C-S-H deterioration is more in NAC as compared to RBAC at high temperatures. There is also an increase in the level of voids in NAC with increasing temperature as compared to RBAC which may be the cause f reduction in residual compressive strength NAC.
3. Ca/Si ratio is, at elevated temperatures, less as compared with NAC which gives more strength due to more content of Calcium Silicates in RBAC. This indicates higher rate of deterioration of C-S-H gel matrix for NAC compared to RBAC at elevated temperatures.
4. XRD analysis of the NAC and RBAC specimens show the presence of quartz, anorthite, calcite, Ettringite, C-S-H (tobermorite), and portlandite. There is higher rate of deterioration of C-S-H in NAC compared to the C-S-H deterioration of RBAC.

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