# Original Research Article

# Effect of locally available Wheat Straw Ash in developing high strength concrete



## ABSTRACT

This study is supervised to assess the characteristics of the locally available wheat straw ash (WSA) to consume as a substitute to the cement and support in enhancing the mechanical properties of concrete. Initially, after incineration at optimum temperature of 800°C for 0.5, the ash of wheat straw was made up to the desirable level of fineness by passing through it to the several grinding cycles. Subsequently, the X-ray fluorescence (XRF) along with X-ray diffraction (XRD) testing conducted on ash of wheat straw for the evaluation its pozzolanic potential. Finally, the specimens of concrete were made by consuming 10% and 20% percentages of wheat straw ash as a replacement in concrete to conclude its impact on the compressive strength of high strength concrete. The cylinders of steel of dimensions 10cm diameter x 20cm depth were acquired to evaluate the compressive strength of high strength concrete. The relative outcomes of cylinders made of wheat straw ash substitution presented the slight increase in strength values of the concrete. Ultimately, the C-100 blends and WSA aided cement blends were inspected for the rheology of WSA through FTIR spectroscopy along with Thermogravimetric technique. The conclusions authenticate the WSA potential to replace cement in the manufacturing of the high strength concrete.

*Keywords: Glenium 110M, Compressive strength, high strength concrete,* X-ray diffraction

## 1. INTRODUCTION

High strength concrete is extensively recognized as a substitution of concrete owing to its enhanced mechanical characteristics [1]. Manufacturing of such concrete consist of low water to cement ratio together with admixtures yields high strength and durable concrete but simultaneously the drop in the internal relative humidity and phenomena of self-desiccation occurred which cause decrease in durability of high strength concrete [2,3]. This possibly will cause the early cracking of the concrete due to heat of hydration and non-availability of water for hydration reaction [4].

For mitigation of the cracking and minimize the consumption of cement in manufacturing concrete, many investigators suggested the idea of incorporation of minerals and admixtures for example stone powder, bentonite clay, cenospheres, wheat straw ash and ash of rice husk [5,6]. The inexpensive materials showed the significant results in enhancing the compressive strength due to pozzolanic characteristics of the materials [7,8]. Thus, between them wheat straw ash (WSA) selected to replace the cement to study mechanical properties of concrete and its impact on the concrete microstructural characteristic. Furthermore, the attributes of amorphous silica in WSA depends widely on its source, climate condition and soil strata [9] as well as various burning temperatures, rate of burning, total burning hours and different grinding cycles have also significant influence on the its properties [10,11]. The

WSA effects on the mechanical aspects of concrete was studied by many researchers and concluded that the WSA when as a substitute to cement up to 30 % yielded the improved results but compressive strength decreases up to 40% utilization of WSA in concrete [12,13]. Moreover, the results of the permeability tests of the concrete aided with WSA showed the reduction in the permeability as compared to control specimen which indicates the greater surface area of WSA and sequentially WSA absorbed more quantity of water [14,15].

Thus, in view of WSA origin, burning temperature, grinding cycles and so on, the role of WSA is still required to investigate the mechanical features of the high strength concrete. Therefore, this research study was carried out on a locally available wheat straw in Khyber Pakhtunkhwa, Pakistan considering its economical and mechanical benefits. Initially, optimum burning temperature was determined by incinerating straw of wheat at burning temperature of 800°C for 30min. Afterward, the appropriate cycles of grinding of WSA in a ball mill machinery at the PCSIR laboratory which is followed by sieving through sieve No. 200 to made sure that its fineness for the pozzolanic reaction with cement. The chemical composition of WSA samples were studied in detail through XRF and XRD analysis to identify different phases present in WSA and to understand the effect these materials characteristics on the strength parameters of concrete at the optimum temperature. Then different percentages of WSA (10% and 20%) used as a substitute to cement for the evaluation of its efficiency. For the precise measurement of compressive strength, concrete cylinders of 10cm diameter x 20cm depth were casted to measure compressive strength of control and WSA aided mixes. Furthermore, microstructural properties were authenticated further by means of FTIR and TGA analysis.

## 2. MATERIAL AND METHODS
### 2.1 MATERIALS

For this research, a locally sourced type-1 and type-3 ordinary Portland cement (OPC) fulfilling the ASTM C150 standards was gained from Kohat cement factory as a chief binding material. The main cement constitution is illustrated in Table-1.

Glenium 110M admixture was got from BSAF, Pakistan fulfilling the ASTM C494 specification to maintain the desired workability of high strength concrete. The basic statistics of Glenium 110M admixture illustrated in Table-2. Coarse aggregates were procured local supplier of maximum 20mm size and passed through various sieves consistent with ASTM C136. The bulk density and water absorption were 102 lb/ft3 and 1.90% respectively of coarse aggregates together with the 20.8% value of Los Angeles Abrasion and 2.70 value of specific gravity. Similarly, fine aggregates of maximum particle size of 2.36mm was obtained of specific gravity 2.64 and fineness modulus 2.7. The graph of gradation curve of aggregates are shown in Figure-1(a,b).

Locally available wheat straw utilize in research was acquired from Mardan, KPK Pakistan. As duration and range of burning of WSA is very significant in defining the phases of amorphous and crystalline silica [16,17] so as to accomplish its amorphous level, WSA was burned under different controlled temperature at 800°C for 30min to assess the pozzolanic characteristics as shown in Figure-2. After incineration, WSA was conceded through various grinding cycles for 2 hr in the ball mill machinery to make it fine so as to satisfy the desired level of refinement. Figure-3(a,b) shows the rotary kiln and the ball mill used in the incineration and grinding of wheat straw respectively. The identification of the major trace of range of elements of WSA was then evaluated by XRD and XRF analysis at the Centralized resource laboratory (CRL), Peshawar. The description of XRD instrument installed as: Model No. JDX-3532 manufacture in Japan with wavelength value up to 1.5418Å and 2θ-Range of

0° to 80°. Chemical composition of WSA at different temperatures obtained from XRD and XRF analysis were evaluated shown in Table-3.

**Table 1. Composition of cement**

| Item | Value |
|---|---|
| **Chemical properties (% by weight)** | |
| SiO2 | 21.9 |
| Al2O3 | 3.27 |
| Fe2O3 | 3.11 |
| SO3 | 3.01 |
| CaO | 63.1 |
| MgO | 2.30 |
| Ignition Loss | 1.30 |
| Insoluble residue | 0.77 |
| **Physical properties (% by weight)** | |
| Blaine fineness (m2/kg) | 3.15 |
| Specific gravity (g/cm3) | 311 |
| Initial setting (min) | 150 |
| Final setting (min) | 235 |
| 28 days compressive strength (MPa) | 42.5 |
| **Compounds** | |
| C3S | 46.97 |
| C2S | 24.61 |
| C3A | 10.22 |
| C4AF | 9.76 |

**Table 2. The basic characteristics of Glenium 110M admixture**

| Particulars | Value |
|---|---|
| Color. | Dark brown liquid |
| Specific gravity. | 1.065 |
| Density. | 1.23 kg/liter |
| Storage provisions. | Store in original containers at above 5ºC and below 30ºC. |
| Dosage. | 1.7–2.0 liter per 100 kg of cement |
| PH value | 5.5 |
| Solubility in water. | Soluble |
| Physiological effect | Non-irritant |

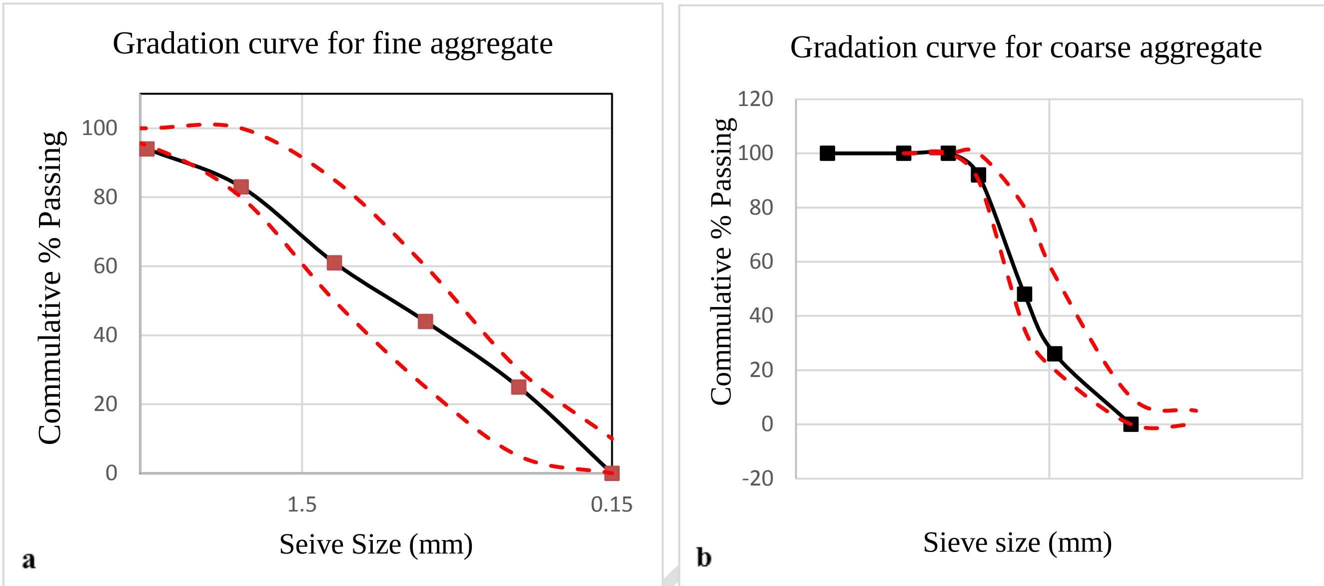


Figure-1 (a,b) Gradation curve (fine and coarse aggregates)

Figure-2 a) Wheat crop b) Wheat Straw separation c) Wheat straw ash burning at 800°C for 30min

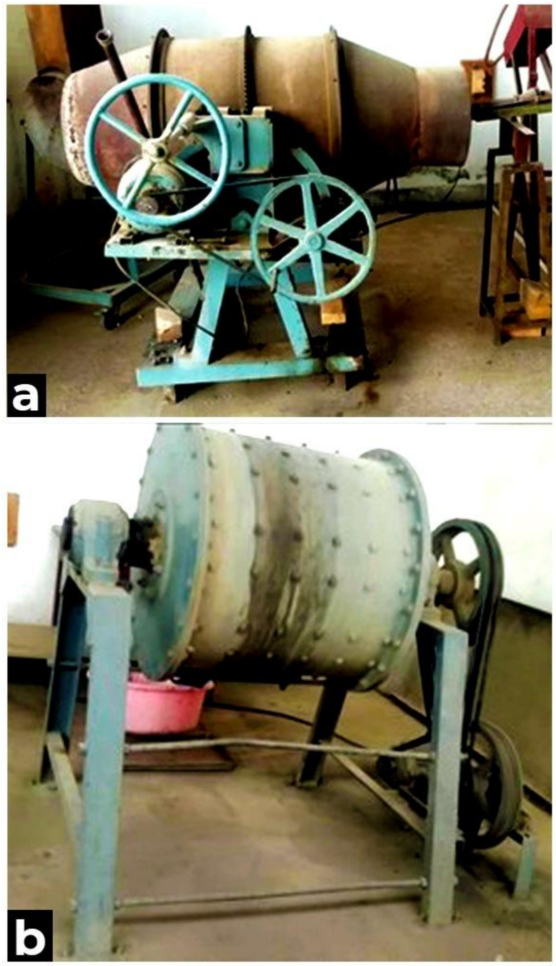


Figure-3 (a) Rotary kiln for incineration of wheat straw at controlled temperatures
(b) Ball mill machine to crush wheat straw ash to make it fine

**Table-3 Chemical composition of WSA under controlled temperatures**

| **Compounds** | **Oxides (% by Weight) Burning Temperature (800°C for 30min)** |
|---|---|
| $SiO_2$ | 61.07 |
| $Fe_2O_3$ | 2.14 |
| $Al_2O_3$ | 7.01 |
| **$SiO_2$+ $Al_2O_3$+ $Fe_2O_3$** | 70.22 |
| $K_2O$ | 16.12 |
| CaO | 8.87 |
| $SO_3$ | 1.06 |

## 2.2 MIXING PROPORTIONS AND PREPARATION OF CONCRETE SPECIMENS

The ACI 211.4R has been followed for mixture proportion to attain the desired strength and durability parameters. The W/C ratio was kept 0.35 for concrete mixture ratio of 1:1.35:2 used in concrete batching together with fine and coarse aggregates which were mixed so as to attain constant w/c ration for all mixes. As high strength concrete is made by utilizing little amount w/c ratio and workability of specimens of concrete were quite low, small dosage of super plasticizer named as Glenium 110M was defined for the mixture proportion to accomplish required level of slump values. Table-4 (a,b) showing the mixture design for concrete cylinders, and for the blended paste specimens intended for microstructure testing. Subsequently, WSA was grind further to examine the fineness on its mechanical properties and the mixes identified as C-100, WSA-10 and WSA-20.

For each mix listed in Table-4a, concrete cylinders of 10cm diameter x 20cm depth were casted separately to assess the compressive and tensile strength tests of concrete in line with ASTM C39 along with ASTM C496 respectively at ages of 7 and 28. Casted samples were completely insulated to avoid moisture loss and moist curing was wholly provided under quality conditions in the laboratory till testing. Then the mentioned tests conducted by utilizing the universal testing machine (UTM) on concrete cylinders and the average values of three identical samples were calculated at all ages as shown in Figure-4 (a,b,c) and the microstructure testing on the cement blend specimens are represented in Figure-5.

**Table-4a Mixture design for concrete cylinders**

| Mix designation | w/c (ratio) | WSA (kg) | CA (10mm) (kg) | CA (20mm) (kg) | FA (kg) | Admixture (ml) |
|---|---|---|---|---|---|---|
| C-100 | 0.35 | 0 | 8.63 | 8.63 | 11.52 | 68.25 |
| WSA-10 | 0.35 | 0.85 | 8.63 | 8.63 | 11.52 | 68.25 |
| WSA-20 | 0.35 | 1.70 | 8.63 | 8.63 | 11.52 | 68.25 |

**Table-4b Mixture design cement blend specimens**

| Mix designation | Cement (g) | WSA (g) | Water (g) |
|---|---|---|---|
| C-100 | 0.35 | 0 | 8.63 |
| WSA-10 | 0.35 | 0.85 | 8.63 |
| WSA-20 | 0.35 | 1.70 | 8.63 |

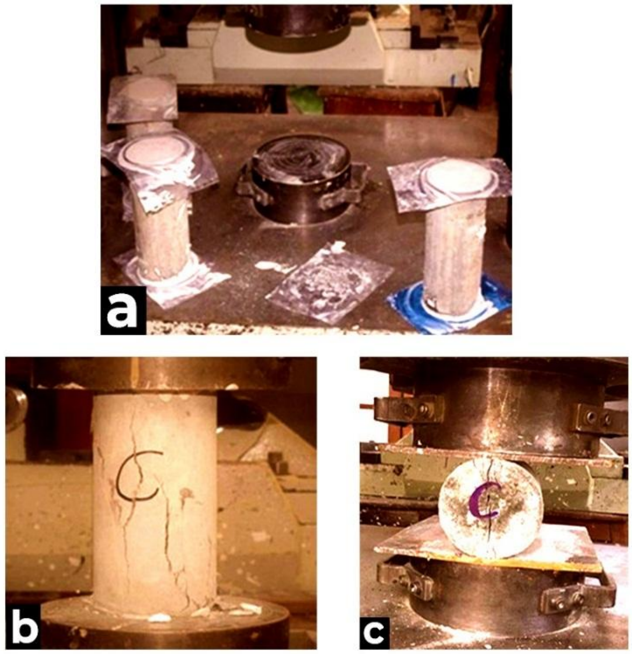


*Figure-4 (a,b,c) Test procedure for compressive strength measurement of concrete cylinders*


**C-100 Blends** **WSA-10 Blends** **WSA-20 Blends**

*Figure-5 Cement blend specimens for microstructure testing*

## 3. EXPERIMENTAL RESULT AND DISCUSSION

As discussed earlier, the results obtained from XRD and XRF analyses on WSA samples incinerated at 800°C for 0.5hr indicates the occurrence of amorphous form of silica which is necessary for pozzolanic reaction. For the burning temperature of 800°C, XRD pattern in Figure-6 indicated a broad and wide peak band at 27.6 value of 2-θ which reflect the high amorphous nature of WSA for pozzolanic reaction.

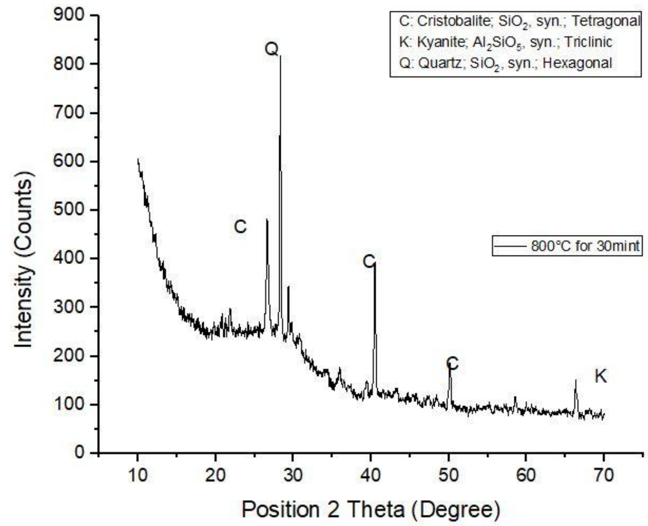


Figure-6 XRD analysis of WSA at incineration at 800°C for 0.5hr

### 3.1 COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE

The compressive and tensile strength tests were performed on samples with and without WSA at ages of 7 and 28 days following the ASTM C39 and ASTM C496. The outcomes got from histogram of compressive and tensile strength tests containing 10 and 20% WSA were slightly more than that of C-100 specimen thus verifying the pozzolanic potential of WSA is in accordance with past research studies on WSA [18,19]. Figure-7 (a,b) explaining the comparative outcomes of compressive and tensile strength obtained from UTM equipment.

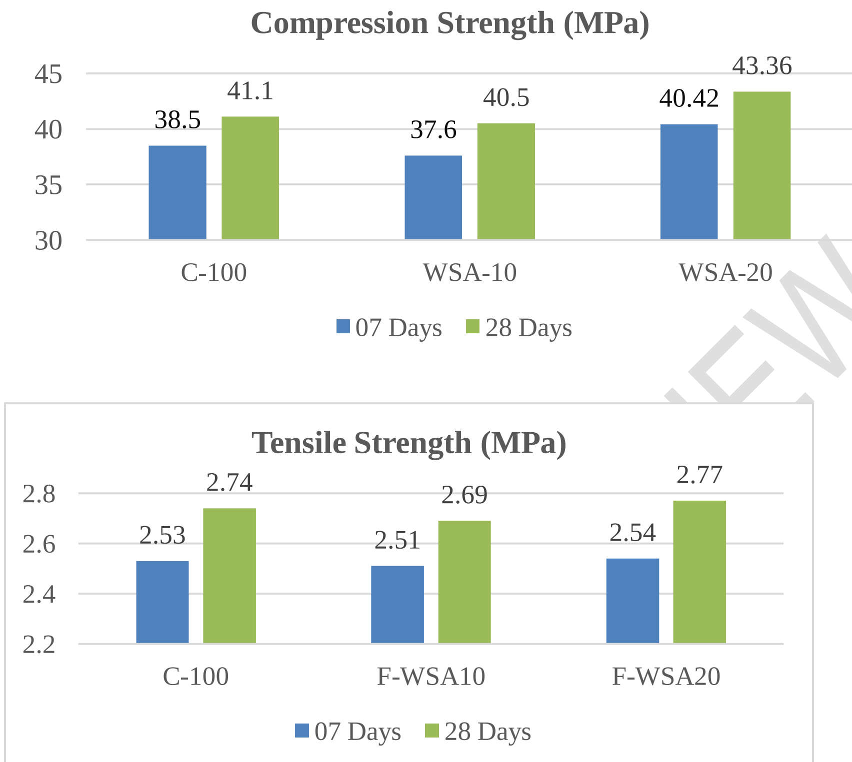


Figure-7 (a,b) Bar chart representation of compressive and tensile strength for all mixes at 7 and 28 days

## 3.2 MICROSTRUCTURAL ANALYSIS ON CEMENT

The C-100 blends and WSA aided cement blends with the help of FTIR and TGA analysis to authenticate the pozzolanic reactivity of WSA.

### 3.2.1 Fourier transform infra-red spectroscopy (FTIR)

It is observed from the stretching among 500 $cm^{-1}$ and 1100 $cm^{-1}$ which shows the Si-O bands of C-S-H as illustrating in Figure-8. The range between 500 $cm^{-1}$ to 900 $cm^{-1}$ indicate the Si-O-Si symmetric and asymmetric bands while C-S-H characteristics and the polymerization process of $SiO_2$ is indicated in change in peak between 900 $cm^{-1}$ and 1100 $cm^{-1}$. The C-100 paste results in 956 $cm^{-1}$ peak value whereas WSA-10 and WSA-20 gave the peaks of 961 $cm^{-1}$ and 965 $cm^{-1}$ respectively in addition to SF-WSA10 and SF-WSA20 which showed the summits of 968 $cm^{-1}$ each. The outcomes obtained from FTIR analysis revealed the WSA addition to the cement paste triggered the shift in peak from asymmetric stretching as in control specimen to the improved rate of polymerization because of high degree of silica formation. Moreover, the occurrence of calcium hydroxide (C-H) content is indicated by the band of sharp summit at 3640 $cm^{-1}$of C-100 cement paste. This intense peak slightly got smooth in F-WSA10 and F-WSA20 blends which specify the drop in C-H content while yielding more compact and denser C-S-H microstructure gel in contrast to the control mix.

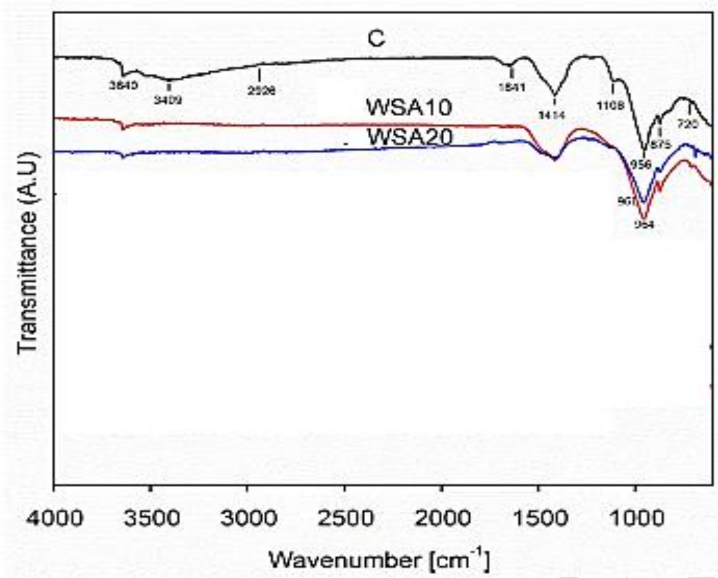


Figure-8 Comparative FTIR results among control cement blend and paste containing WSA

### 3.2.2 Thermogravimetric analysis (TGA)

In addition to the FTIR analysis, this research has further examined the WSA effect on the pozzolanic reaction of concrete. The outcomes obtained from the TGA analysis conducted on a control paste and WSA aided pastes for 28 days demonstrated the percentage of weight loss in the samples at different temperatures as shown in Figure-9. The initial phase of the comparative graph indicated the evaporation of water between temperature range of 30°C-100°C. The calcium silicate hydrate (C-S-H) drying out was occurred in the next stage at the temperature between 100°C to 350°C. The subsequent phase from 400°C to 450°C presented the breakdown of calcium hydroxide in the course of the phenomena of hydration [20]. TGA analysis evaluate the depletion of $Ca(OH)_2$ with aging and hence indicate the pozzolanic potential of the material [21]. The relative graph obtained from TGA analysis demonstrated that the maximum amount of weight loss held in the control specimen at 400°C to 450°C regardless of moist curing which specifies the continuous generation of $Ca(OH)_2$ during hydration phenomena. Instead, the weight loss in the cement blends comprising of WSA showed the smoothness in the slopes as compared to steep slopes of C-100 sample. The minimum weight loss was detected in the 20% WSA which represents its utmost potential for hydration reaction.

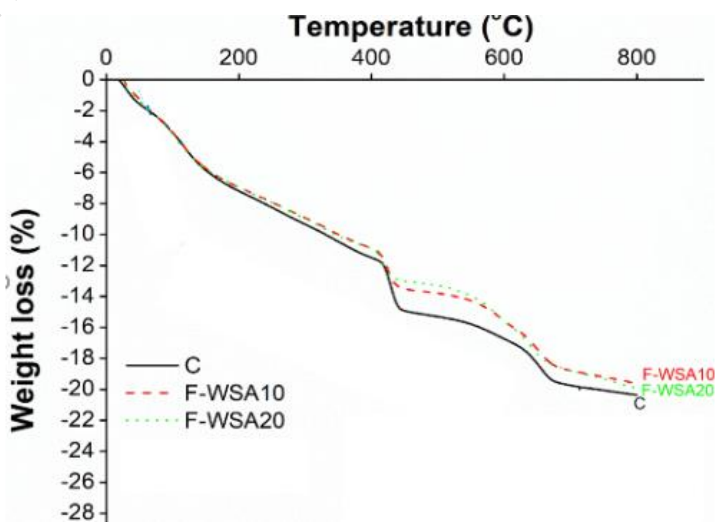

Figure-9 Comparative TGA results among control cement blend and paste containing WSA

## 4. CONCLUSION

In this research, the pozzolanic performance of local agriculture byproduct wheat straw ash (WSA) was studied and its potential usage in manufacturing of high strength concrete. Initially, the optimum incinerating temperature of 800°C for 0.5hr was selected on the basis of XRD and XRF analysis which indicated the maximum amount of reactive silica in amorphous form which was then passed from several cycles of grinding to get the desired level of fineness. Finally, mix design of control mix and 10 and 20% of WSA was designed. Subsequently, mechanical tests and microstructural analysis performed on the WSA mixes to validate its potential to use as substitute to cement for manufacturing of high strength concrete. In accordance with outcomes, the decisions were drawn from research:

- It is observed from the XRD and XRF results that the fundamental elements such as $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ in WSA are abundant as per ASTMC618.
- High strength concrete PC batching comprising very low w/c ratio and the workability of concrete reduced further by the addition of different percentages of WSA. Hence, different doses of the Glenium admixture were aided to get the desired level of workability.
- The compressive strength results of concrete have improved significantly at all ages for 7 and 28 days when WSA used as a partial substitute to cement as compared to control sample.
- Moreover, the pozzolanic potential of WSA was authenticated further by FTIR results which indicated the conversion of C-H into C-S-H gel by a change in the peak from 956cm-1 to 968cm-1. FTIR results were further supported by TGA analysis conducted on the cement pastes which showed the exceptional improvement in the pozzolanic reactivity when WSA utilized as a substitute to cement in concrete.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.



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