Grenze International Journal of Engineering and Technology, June Issue

Experimental Investigation on the Strength Properties of Agro-Waste Ash and Industrial Waste in Mortar

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***Abstract*— As construction materials, agro-industrial by-products have been considered as a partial replacement of cement and fine aggregates due to the increasing pressure to establish sustainable and economical building materials. This experiment examines the synergistic effect between Wheat Husk Ash (WHA), an agro-waste composed of amorphous silica, and Quarry Dust (QD), an industrial waste originating from crushing stone, in an MM7.5 grade mortar with a 1:3 ratio of cement to sand. Cement was substituted by WHA at varying degrees of 5, 10, 15 and 20 with QD substituting sand at the same rate in reverse proportions (20, 15, 10, and 5). The performance and durability of the products in compressive strength (7, 14, and 28 days), water absorption, and adhesion strength were tested. Findings obtained that moderate replacement with particular 10% WHA and 15% QD gave the best compressive strength with less water absorption, and this means better matrix density. WHA helped to strengthen in the long term due to pozzolanic reactions, whereas QD helped to increase the early strength and decrease porosity. The use of the composite materials was found to be effective in the production of environmentally friendly, durable and cost-efficient mortar, which does not rely on natural sand and cement, but instead on adhesion strength and water absorption at 28 days. It was found that the addition of WHA and QD increased mechanical and durability properties. The combination of 10 per cent WHA and 15 per cent QD produced the best 28 per cent compressive strength and a minimum percentage of water absorption, which reflected better pore refinement and bond strength. On the whole, the research comes to a conclusion that the use of WHA and QD not only enhances the performance of mortar but also provides a cost-effective and sustainable method of minimising environmental pollution and dependence on conventional building materials.**

***Index Terms*— Wheat Husk Ash (WHA), Quarry Dust (QD), Sustainable Mortar, Compressive Strength, Pozzolanic Activity, Agro-Industrial Waste Utilization.**

I. INTRODUCTION

The world construction market is coming under pressure to pursue sustainable, low-carbon and resource-efficient building solutions as a reaction to the mounting environmental issues and scarcity of natural raw materials. The cement production contributes to the total CO emission worldwide almost 8 per cent, which is why the necessity to find alternative auxiliary materials is urgent and critical [1].

Grenze ID: 01.GIJET.12.2.362_22

On the same note, the over-exploitation of natural river sand has resulted in the ecological degradation of the riverbed, erosion, and insufficiency of supply, with the necessity of sustainable fine aggregate replacements [2]. In this regard, agro-industrial wastes have become one of the potential candidates to replace cementitious composites partially. Wheat Husk Ash (WHA) is an agricultural by-product, which is composed of amorphous silica and has pozzolanic activity equal to that of other plant-based ashes like Rice Husk Ash (RHA) due to the burning of wheat husks. Fine-ground and well-compounded WHA may positively influence the microstructure of mortar by creating more calcium silicate hydrate (C2SH), which provides superior strength in the long term and lowers permeability. Conversely, Quarry Dust (QD), a manufactured industrial waste, which is readily available in stone crushing, is more angular and has high packing density, which also makes it an effective substitute for natural sand in mortar and concrete mixes.

It has been proven that, with respect to using ideal proportions, the use of cement can be substituted with pozzolanic agro-ashes, as well as natural sand can be replaced by QD to improve mechanical and durability characteristics. There is, however, little research that has been conducted on the combined use of WHA and QD in mortar mixes, especially regarding lower-grade mixes like MM7.5, that are regularly applied in the masonry, plastering and general construction practices. This research paper examines the synergetic effect of WHA and QD on compressive strength, water absorption and adhesion strength of mortar. The study helps in sustainable construction practices through the incorporation of agro-waste and industrial waste, and the reduction of the environmental load, as well as the enhancement of the principles of the cyclical economy.

II. Review of Literature

In the study conducted by Bouzoubaa and Fournier (2001), the pozzolanic reactivity of different agricultural ashes in cementitious systems was determined. They discovered that ashes that had amorphous silica enhanced compressive strength by enhancing secondary hydration reactions. They found that low replacement rates (5-15 per cent) result in high levels of durability, especially in chloride penetration resistance. Another observation of the authors was that the fineness of ash and the temperature of burning are also significant factors in performance results. This research justifies the use of agro-ash as a good SCM. [3]

Mehta and Monteiro (2014) highlighted the importance of supplementary cementitious materials based on agro-wastes in improving concrete performance. Their study described the contribution of ashes that are high in amorphous silica (WHA and RHA) to further C-S-H formation in the form of a pozzolanic reaction. This causes long-term compressive strength and durability. These also were found to have been emphasised by the authors when using such ashes in controlled quantities: microstructural densification and refined pore connectivity. Their activity creates a background knowledge concerning the action of agro-ash in cement-based composites. [4]

Ilangovana et al. (2008) offered quarry dust as an alternative material to natural sand in mortar and concrete. Their findings revealed that quarry dust improves the mechanical strength because of its angular shape of particles, enhancing the bond between the particles. This research revealed that there were great diminutions in void content and heightened densities in mixes. They concluded that up to 25-30 per cent of sand can be substituted by QD, and the structural performance will not be affected. This piece advocates for the recycling of industrial waste in building. [5]

Singh et al. (2020) explored the study of industrial by-products and agro-ashes as a mixture in mortar. Their results showed that these combinations have a strong positive effect on the mechanical strength through refining the pore structure and decreasing microcracks. Experiments indicated a high level of compressive, water-tightness, and bonding. They emphasised that hybrid substitutes have synergies as opposed to the applications of single materials. The study justifies the incorporation of multi-waste systems towards sustainable construction. [6]

Thomas and Harilal (2017) examined the application of agro-waste ashes in mortar and concrete to determine their impact on the duration. They said that ashes like WHA and RHA enhance water penetration, sulfate attack and chemical deterioration resistance. The research indicated that the best replacement levels (10-15 per cent) have a great effect on decreasing water absorption and porosity. The authors highlighted the significance of controlled burning and fine grinding in order to achieve maximum pozzolanic activity. The findings by them favour the use of agro-waste ashes in long-lasting construction products. [7]

Chouhan and Kumar (2019) experimented with the use of husk ash of wheat as a substitute for cement in mortar. They noted that 10 per cent WHA replacement had maximum compressive strength as the pozzolanic activity is enhanced. The experiment affirmed an increase in microstructure, a decrease in shrinkage, and a decrease in permeability. The authors pointed out that WHA should be grounded and should be well-calcined to be effective. Their results confirm that WHA is a good option for green cement. [8]

Patel and Shah (2018) discussed the positive impact of using quarry dust instead of natural sand in mortar mixes. Their analysis showed higher density, increased bonding among the particles, as well as the early-age strength. They credited these advancements to the fineness and angularity of quarry dust, which improves the efficiency of packing. The authors also mentioned an increase in the adhesion strength when applied in plastering. Their article supports the use of QD as a sustainable construction material. [9]
Banerjee and Prasad (2019) have conducted a review of the use of agricultural waste ashes in cement composites as a sustainability measure. They indicated that such ashes that include WHA enhance mechanical strength when incorporated in controlled proportions, and this is largely because of the silica in them. Some of the environmental advantages they found in their study include the lower usage of cement and waste. The authors did not neglect the contribution of ash fineness to the establishment of the efficiency of pozzolanic. This review justifies WHA as an eco-friendly building material. [10]
Akinwumi et al. (2016) evaluated the behaviour of different agro-waste ashes in mortar and concrete. When ashes were treated well, they realised significant gains in compressive strength and endurance. The experiment brought out an improvement in resistance to water absorption and chemical attack, particularly in moderate levels of replacement. The authors emphasised the importance of controlled calcination to maximise the amorphous silica. Their results encourage the use of agro-waste materials in building sustainably. [11]
Kumar et al (2021) investigated the use of sugarcane bagass in the production of stabilized adobe bricks. Their study examined the effect of varying ash content on mechanical and durability properties. [12]

III. MATERIAL TESTING

A. Cement (OPC 53 Grade)

Ordinary Portland Cement of 53 grade was used for all mortar mixes in the study. The cement is within the limits given in IS 12269:1987. The initial and final setting time is 30 min and 600 min minimum , find using vicatus apparatus shown in fig (1) . OPC 53 grade cement is used for research because of its ability to give high early strength due to the higher proportion of tricalcium silicate (C_3S) present in it as compared to the other type of cement and grade. The cement used was fresh, lump-free, and stored in dry conditions to prevent moisture which can cause its hardening.
Physical properties of OPC Cement of grade 53 were obtained by testing and are mentioned in Table I.

TABLE I. PHYSICAL PROPERTIES OF CEMENT OPC 53 GRADE

Sr. No.	Property	IS Code	Result
1	Standard Consistency	IS 4031 (Part 4)	As obtained in laboratory
2	Initial Setting Time	IS 4031 (Part 5)	> 30 minutes
3	Final Setting Time	IS 4031 (Part 5)	< 600 minutes
4	Specific Gravity	IS 4031 (Part 11)	3.15

Figure 1. Setting Time (Vicatus Apparatus)

B. Fine Aggregates

Fine aggregate used in the study were Natural River Sand, Quarry Dust and Wheat Husk Ash. Natural sand used was of Zone II grade as per IS 383. Quarry dust and wheat husk ash were taken as partial replacements to study how they affect the strength and durability of the mortar.

Natural Sand

Natural River Sand used, was clean, free from organic impurities and well graded. It provided adequate workability and bonding in MM7.5 grade of mortar.

C. Quarry Dust

Quarry dust which is an output obtained from the stone crushing process in quarries. It has angular particles and its surface texture is rough shows in figure 2 us, which helps in better bonding and results in tightly packed particles when used as a partial replacement for sand.

D. Wheat Husk Ash (WHA)

Wheat husk ash is formed by controlled burning of wheat husk at temperatures in the range of 600°C and 700°C. The ash was passed through a 75 µm sieve before adding to the mortar mix. As it has fine and porous nature, Wheat Husk Ash shows pozzolanic properties and helps in strength development.
Physical properties of fine aggregates are given in Table II.

TABLE II: PHYSICAL PROPERTIES OF FINE AGGREGATES

Material	Specific Gravity	Water Absorption (%)	Remarks
Natural Sand	2.60	1.0	Zone II grading
Quarry Dust	2.45	1.3	Angular particles
Wheat Husk Ash	2.20	8–15	Very fine and porous

Figure 2. Sieve Analysis

E. X-Ray Fluorescence (XRF) Analysis

X-ray Fluorescence (XRF) analysis was done on Quarry Dust and Wheat Husk Ash to understand their chemical composition. This test benefits in knowing the presence of Elemental and Oxide components in the materials. Table III shows non-oxidized components & Table IV shows oxidized components below:

TABLE III. NON-OXIDIZED COMPONENTS (ELEMENTAL)

Element	WHA	Quarry Dust
Silicon (Si)	High	Moderate
Aluminium (Al)	Low	Moderate
Calcium (Ca)	Low	Moderate
Iron (Fe)	Trace	Low
Magnesium (Mg)	Trace	Trace

TABLE IV: OXIDIZED COMPONENTS (OXIDES)

Oxide	WHA (%)	Quarry Dust (%)
SiO_2	85–95	60–70
Al_2O_3	2–5	10–15
CaO	1–3	5–10
Fe_2O_3	< 2	3–5
MgO	< 1	< 2

The XRF results suggests that wheat husk ash has a high proportion of silica leading to its pozzolanic nature. Quarry dust suggests Moderate silica and alumina present in it, which results in improved tightness among the particles and strength when used as a replacement of Natural Sand.

IV. METHODOLOGY

A. Materials Used

- Cement: Ordinary Portland Cement (OPC 53 Grade) as per IS 8112:2013.

- Fine Aggregate: Natural River Sand as per IS 383:2016.
- Quarry Dust: This is of local stone crushed plant, sieved with a 4.75 mm IS sieve.
- Wheat Husk: Wheat Husk is picked up in the surrounding farms, dried, and burnt in a furnace with a temperature of about 700 °C to make Wheat Husk Ash (WHA). The ash obtained was sieved and ground to a fine of 75 µm to uniform fineness.

B. Material Testing

To ascertain the material properties in accordance with the applicable IS standards, physical and chemical tests were carried out. Fine Aggregate Tests -Fine Aggregate (IS 2386:1963 Part I to III):

- Specific Gravity
- Water Absorption
- XRF

C. Mix Proportioning

The proportion of mortar mix was established at 1:3 (Cement: Sand) by weight according to IS 2250:1981. All mixes had a water-cement ratio (w/c) of 0.52 to provide consistency. Control Mix: 0 per cent WHA and 0 per cent Quarry Dust figure 3.

Figure 3. Materials Mixing

D. Mortar Cubes Preparation and Casting

- The ready mortar was poured into cube moulds of 70.6 mm diameter in three layers, the layers being pressed down to 25 gentle strokes.
- The upper surface was flattened and smoothed off ,in figure 4.
- The specimens were left to dry after 24 hours at room temperature, and then demoulded.
- Triplicated each mix was done, and this means that there were three cubes per curing period (7, 14, and 28 days).

Figure 4. Mortar Mould

V. Result and Discussion

A. Compression strength with quarry dust and water absorption

Compressive Strength of Mortar with Quarry Dust for 7, 14, 28 days and its corresponding water absorption after 28 days of curing are given as below in Table V and Figure 5 represent the result in graphical form:

TABLE V. COMPRESSION STRENGTH WITH QUARRY DUST (FOR 7, 14, 28 DAYS) AND WATER ABSORPTION (AFTER 28 DAYS)

Mix Code	Quarry (%)	7 Days (MPa)	14Days (MPa)	28Days (MPa)	Water absorption %
CQ0	0%	11.46	15.86	18.63	9.5
CQ5	5%	12.44	17.7	19.4	9.2
CQ10	10%	14.34	18.3	21.2	8.7
CQ15	15%	14.7	17.9	19.93	8.5
CQ20	20%	15.1	19.4	23.3	8.3

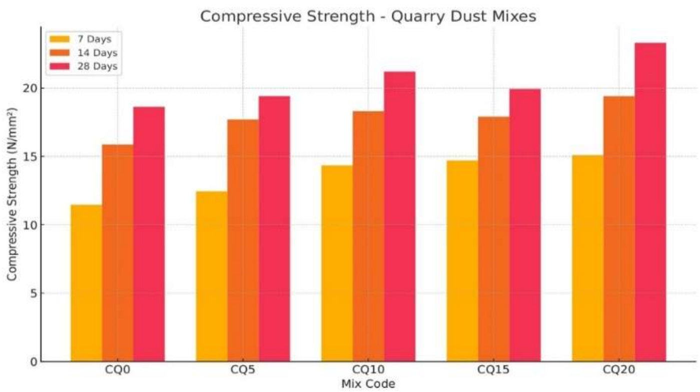

Figure 5. Compression Strength – Quarry Dust

B. Compression Strength Quarry Dust And WHA

To evaluate synergy, combinations of WHA and quarry dust were tested, totalling 20% sand replacement. The results show nearby equal early and later strength with reduced water absorption compared to mixes made only using Wheat Husk Ash. Compressive Strength of Mortar with Quarry Dust and Wheat Husk Ash for 7, 14 and 28 days and its respective water absorption results after 28 days of curing are tested and shown in figure 6, the results are given below in Table VI and Figure 7 represent the data in graphical form:

TABLE VI. COMPRESSION STRENGTH WITH QUARRY DUST AND WHA (FOR 7, 14, 28 DAYS) AND WATER ABSORPTION (AFTER 28 DAYS)

Mix Code	WHA (%)	Quarry	7Days (MPa)	14Days (MPa)	28Days (MPa)
MW0Q20	0	20	7	11.2	15.8
MW5Q15	5	15	7.5	10.7	15
MW10Q10	10	10	7.5	9.5	14.5
MW15Q5	15	5	7.6	10.5	14
MW20Q0	20	0	7.2	10	12.1

Figure 6. Compression Testing Machine

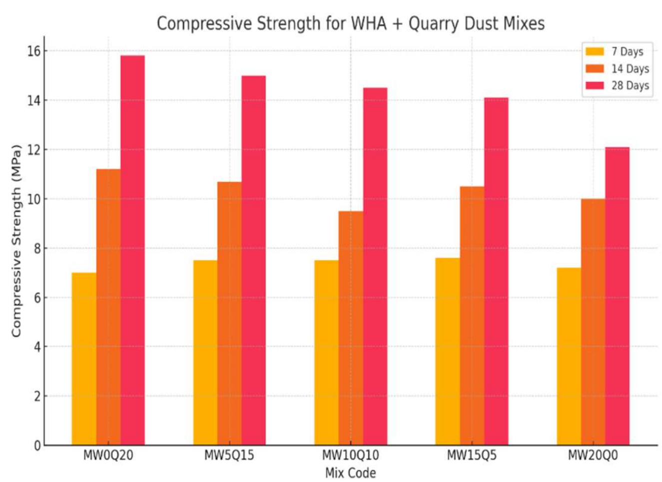

Figure 7. Compressive Strength – Quarry Dust & WHA

C. Water Absorption Behaviour

The water absorption of mortar increases remarkably with surkhi because of its porous, brick derived composition, whereas quarry dust has lower absorption and their combined use gives an overall practical option. The results were obtained using Oven Drying Method shown in Figure 9, Table VII shows water absorption results and the same are represented in graphical form in Figure 8.

TABLE VII: WATER ABSORPTION OF SURKHI, QUARRY DUST, AND COMBINED (AFTER 28 DAYS)

Mix Code	WHA (%)	Quarry Dust (%)	Water Absorption (%)
MW0Q20	0%	20%	6
MW5Q15	5%	15%	6.2
MW10Q10	10%	10%	6.4
MW15Q5	15%	5%	7.2
MW20Q0	20%	0%	8

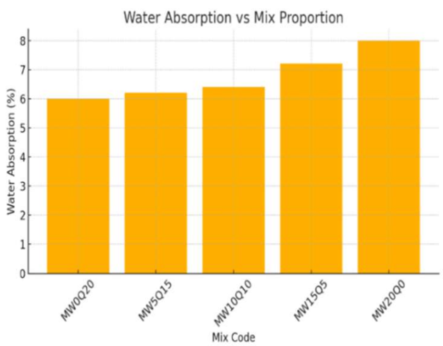

Figure 8. Water Absorption in % (Wheat Husk Ash, Quarry Dust & Combined)

Figure 9. Oven Drying for Determining water Absorption

D. Adhesion Strength

The adhesion strength of the mortar mixes shows an increase as the proportion of quarry dust increases and the amount of wheat husk ash decreases. Mixes with higher WHA content exhibit lower adhesion because WHA is lightweight, porous, and less dense, reducing contact bonding with the substrate. As WHA decreases and quarry dust increases, the mortar becomes denser and more compact due to the angular and fine particles of quarry dust, which enhance mechanical interlocking. Table VIII states the results of adhesion strength and figure 10 represent it in graphical form.

TABLE VIII: ADHESION STRENGTH

Mix Code	Adhesion Strength (N/mm2)
MW0Q20	1.18
MW5Q15	1.25
MW10Q10	1.32
MW15Q5	1.36
MW20Q0	1.47

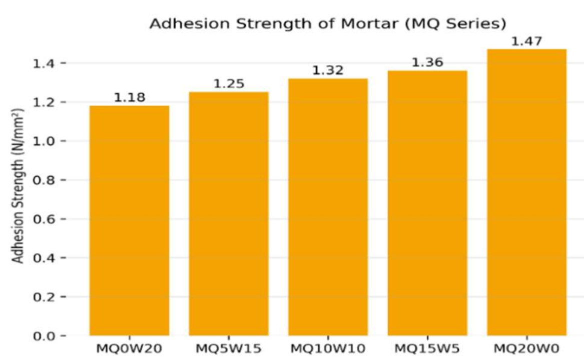

Figure 10. Adhesion Strength

VI. Findings

A. Wheat Husk Ash (WHA)

Use Mortars with WHA exhibited a marginally reduced early-age strength (7 and 14 days) because of the slow reaction of pozzolans and high silica content, taking a longer period to become active. Nevertheless, when the mixes were 28 days old, the mixes with 10-15% WHA showed a high increase in compressive strength because more C-S-H gel was formed as a result of pozzolanic activity. The maximum strength was reached at 15 per cent WHA replacement with approximately 15 MPa after 28 days, though higher strength (20 per cent) showed a slight decrease in strength. As shown, there was a slight increase in water uptake with the WHA content of between 8.0% and 10.5% due to the porous and fine texture. Nonetheless, it led to the enhanced internal curing and development of the long-term strength.

B. Quarry Dust (QD)

Mortars with a partial sand replacement by QD had a higher compressive strength at all of the curing ages as compared to the control mix. Dense and angular shapes of QD particles enhanced the packing density and inter-particle bonding, leading to increased early and long-term strength. The highest 28-day strength was noted at 20 per cent QD replacement, where it was 23.3 MPa, which is close to 25 per cent improvement over the control mix. The absorption of water was reduced significantly together with QD concentration, falling to 8.3 per cent at 20 per cent substitution, denoting improved compactness and decreased voids in the matrix.

C. Wheat Husk Ash with Quarry Dust

WHA + QD was the most balanced in their performance by taking advantage of the strength-enhancing properties of QD and the pozzolanic properties of WHA. The 5% WHA + 20% QD mix had a 28-day compressive strength of 13.0 MPa, with 10% WHA + 15% QD and 15% WHA + 10% QD mixes showing the 28-day compressive strength of 14.0 MPa and 15.0 MPa, respectively. The water absorption of the combined mixes reported between 8.0 and 9.5 per cent, and lower than WHA-only mixes, showing a superior pore refinement. WHA addition enhanced adhesion strength by increasing the fine particle packing and enhancing bond formation, with the maximum adhesion strength of 1.32 MPa with the 10% WHA + 10% QD mixture.

VII. Conclusion

This current researched discussed the implications of Wheat Husk Ash (WHA) as a partial substitute of cement and Quarry Dust (QD) as a partial substitute of fine aggregate in MM7.5 grade mortar. The findings proved that with the addition of agro-industrial wastes, mechanical and durability properties can be greatly improved with the addition of agro-industrial wastes in appropriate ratios. The high amorphous silica content in WHA helped to increase the long-term strength with the help of a pozzolanic reaction, whereas QD increased the early strength and decreased the porosity with its angular particle shape and high packing density. Out of the different combinations that were tested, it was found that the mix with 10% WHA and 15% QD had the highest compressive strength after 28days, the lowest water absorption and the best adhesion strength. This combination is optimal to suggest that WHA and QD used together lead to the denser and more refined microstructure of the material, and further boosts the overall performance. Strength and durability at higher replacements depicted downward trend because of decreased cementitious material and increased ash content and there was need to restrain substitution. On balance, the research proves the hypothesis that WHA and QD can be successfully applied as the sustainable alternatives in the production of mortars. Their combination alleviates the reliance on natural sand and cement; not only that but also, they also provide an ecologically sound way of dealing with agricultural and industrial waste. Additionally, the findings suggest the possibility of introducing these materials for use in non-structural and general construction settings that utilise MM7.5 grade mortar. The study is applicable to sustainable construction and supports the concept of utilising waste-based mortar technology to promote the use of resource-efficient, cost-effective, and environmentally friendly building materials.

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