# Rice Husk Ash: is it a good substitute for cement in concrete?

**Runcio Edoardo[1], Somma Giuliana[2]**

[1] *Dr. Eng., Polytechnic Department of Engineering and Architecture, Udine, Italy, edoardo.runcio@uniud.it*

[2] *Assistant professor, Polytechnic Department of Engineering and Architecture, Udine, Italy, giuliana.somma@uniud.it*

**Abstract**

Italy alone produces 460,000 tons of rice husk per year, from which, in addition to exploiting the calorific value of combustion for centralized water heating, ash could be used in the production of concrete. In this way, it would be possible to exploit a material that otherwise has no further uses: not only to produce heat, but also as a substitute for cement. This is possible because the obtained ash is made up of over 85% silicon dioxide, that develops a strong pozzolanic activity. In this study the results obtained from laboratory tests on concrete samples, made with an increasing percentage of cement replacement with rice husk ash are analyzed. Two fundamental parameters are taken into consideration: the compressive strength at different maturation periods of the material and its workability, with the use of different water/cement ratios and fluidifiers. It is observed that the concrete resistance reaches a peak for RHA replacement between 5 and 15%, causing only a relative loss of workability, which can easily be recovered with the use of plasticizers. A coefficient has been calculated that can be adopted as a reference for the "environmental" performance of concrete, defined as the ratio between resistance and emissions, and its behavior has been studied by varying the percentage of RHA replacement.

## 1 Introduction

In all European countries, national regulations in terms of environmental sustainability are becoming increasingly stringent, requiring the use of increasing percentages of nature-friendly materials. In a construction sector that is still strongly linked to the use of traditional materials such as concrete, the weight on global $CO_2$ emissions linked to the production of clinker is around 8% [21]. To start an ecological transition in the construction world, three different paths can be pursued: a) to use alternative materials other than concrete, whose production has a lower impact than the latter, b) to reduce the use of cement and therefore clinker in the mixtures and c) to reduce the quantity of concrete in the structure. Wanting to pursue the second of the two hypotheses formulated, today's professionals do not have many alternatives, as the regulations are often contradictory to the technical standards of the sector, creating confusion and making their application more difficult. The result is that the materials for which the use is permitted are very few and often the designer, forced to respect certain sustainability parameters, must use extremely expensive materials that are not locally available, which with their transport have a much greater impact than traditional ones. On the other hand, there are various waste materials available on the national territory from the most diverse production processes, with properties equivalent or even better than those indicated in the regulations, ready to be exploited for the preparation of high-performance mixtures. This study presents one of these materials with a high potential but which is not yet known: the ash deriving from the combustion of rice husks. In the continuation of this document, its chemical-physical and mechanical properties will be presented in case of use as a substitute for cement within the concrete mix, highlighting the advantages that can be achieved compared to a traditional one. Thirteen scientific studies (from [8] to [20]) were considered that evaluated the compressive strength of concrete with an increasing percentage of cement replacement with RHA and an attempt was made to define an overall trend of the behavior of the mixture as this parameter varied. After defining the optimal percentage of cement replacement with RHA, the $\beta_{CO2}$ efficiency index was calculated for each of the mixtures analyzed, which represents the ratio between strength and carbon dioxide emissions.

## 2 Rice husk and rice husk ash

Rice is one of the most widespread foods in the world: it is grown in over 100 countries and covers over 162 million hectares, which guarantee an annual production of 1.2 billion tons of food. In Italy alone, 230,000 hectares are cultivated, from which, on average, 57 million bales of straw are generated, part of which is made up of rice husks: thanks to the high availability of this material, it is therefore possible to promote its use in concrete [1] [2]. Rice husks are a waste product resulting from the food refining process and represent the "husk" of the single seed, which is removed following drying with a process called "husking": compared to the grain that is harvested, it can be considered that approximately 70% becomes rice ready for consumption, 20% is represented by the husk and 10% by the chaff. From an average production it is possible to consider that for each hectare of cultivation 2 tons of husk are obtained, therefore in Italy alone every year there would be available approximately 460 000 tons of husk that can be incinerated and used as a substitute for cement, allowing not only to reuse a material that otherwise has no relevant effective use, but also reducing the quantity of clinker used and consequently the carbon dioxide emissions.

Fig. 1 Aspect of rice straw, rice husk and rice hulls (figure for illustrative purposes only) [1] [22] [23]

## 2.1 Chemical composition

Rice husk is characterized by a variable percentage of carbon between 30% and 50%; it is made up of 50% cellulose, 25-30% lignin, 15-20% silica and the remaining part is made up of the humidity of the material. The specific weight is around 90-150 kg/m$^3$ (depends on the zone, usually 100 kg/m$^3$) and, if brought to combustion, its calorific value on average reaches 15 MJ/kg; therefore, at an Italian level, wanting to bring the husk to incineration, 6,900,000,000 MJ of heat could be generated [3].

The properties of the ash depend substantially on two main factors, the combustion temperature and the exposure time in the oven: the main substances that are obtained are silicates, however, by modifying the parameters just described, very different characteristics can be obtained. In an uncontrolled combustion process, two main components are quickly produced: cristobalite and tridymite. On the other hand, by carrying out a controlled combustion process within a temperature range between 500°C and 700°C for about an hour, the organic components (cellulose and lignin) are lost, obtaining only amorphous silica: this form of silica is more reactive than that deriving from uncontrolled combustion (crystalline silica), thus ensuring the development of pozzolanic properties. The structure of amorphous silica, if analyzed at a microscopic level, is microporous, therefore with a large surface area, which favors its chemical reactivity: it is therefore not advantageous to grind the ash very finely, since the dimensions of the surface area of the particles would be reduced, reducing the pozzolanic activity [4] [5].

Rice husk ash (RHA) with controlled combustion has the following composition [6]:

- Silicon dioxide ($SiO_2$): 87.2%
- Aluminium oxide ($Al_2O_3$): 0.15%
- Ferric oxide ($Fe_2O_3$): 0.16%
- Calcium Oxide (CaO): 0.55%
- Magnesium oxide (MgO): 0.35%
- Sulphur trioxide ($SO_3$): 0.24%
- Carbon (C): 5.91%
- Potassium oxide ($K_2O$): 2 %

The particles have a size of around 7 µm (96% passing through a 45 micron sieve), a specific surface area of 27,400 m$^2$/kg and a pozzolanic activity index of 84%; the loss on ignition value is 5.44%. The bulk density is in general 15.9 kg/m$^3$, but it can change in function of the geographical position. This study considers articles in which specimens containing class 42.5 and 52.5 Portland cement respectively have been used and therefore it will be expected that the results will not be directly comparable, but that all curves must be dimensionless with respect to their reference strength (without substitution), so as not to be affected by the difference in the type of mixture.

As previously described, rice husk has the tendency to absorb a high quantity of water and therefore, hence it can be mixed to the cement in one of the two following ways:

i) to grind the rice husk ash particles together with the cement during its production phase: in this way the structure of the ash is broken and the water requirement is reduced;

ii) to mix RHA and cement on site: in this way the ash can fix the free lime that is released by the clinker in the hydration phase. Amorphous silica reacts with calcium hydroxide ($Ca(OH)_2$), forming in the secondary hydration reaction a C-S-H (calcium silicate hydrated) gel, characterized by a porous structure with a high specific surface area: in this way the resistance and durability of the concrete are increased.

The second procedure is considered more applicable to the construction world as it is more practical, the following sequence of phases has been observed [7]:

1. Reaction of the silicates present in the cement with water, with the breaking of the silicate bonds and formation of the C-S-H and calcium hydroxide gel (the first of the two guarantees the mechanical resistance of the concrete and the second maintains an alkaline environment, protecting the reinforcing steel from oxidation);
2. At a slower but equally effective rate, the reaction between amorphous silica and lime leads to the formation of further C-S-H gel, with an increase, thanks to the ash, in strength and workability in a more diluted time.

## 2.2 Compressive strength

In this study data of 13 tests (from [8] to [20]) done by other authors from 2011 to 2022, have been considered to evaluate the influence of replacing cement with RHA on the compressive strength. The tests considered are made on samples having a water to cement ratio between 0.35 and 06. The durability has also been considered, observing the compressive strength from 7 to 9 days. It must be highlighted that this collection of data is the most numerous nowadays available in literature. The characteristics of the mixtures considered are reported in Table 1. For each water/cement ratio range, the behavior of the mixture is evaluated by varying the percentage of replacement of the cement with rice husk ash: since the workability progressively decreases with increasing replacement, it was decided to keep the w/c constant and use fluidifying additives.

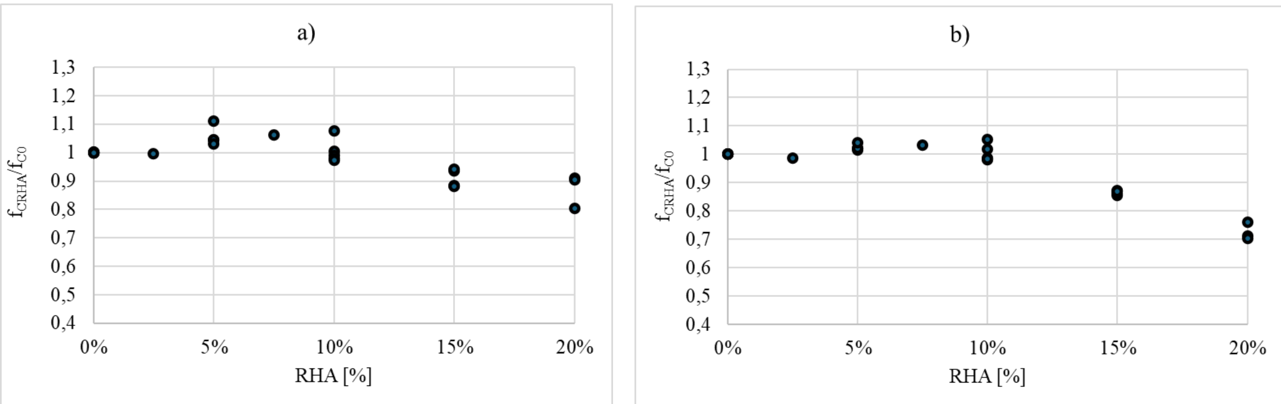
Table 1 Composition of the concrete specimens considered in the test campaign performed

| Reference | N° | ID | Aggregates [kg] | | Water [kg] | Cement [kg] | RHA [kg] | W/C | Cement replaced by RHA [%] |
|---|---|---|---|---|---|---|---|---|---|
| | | | Fine | Coarse | | | | | |
| [8] | 1 | RHA-0 | 559 | 830 | 232 | 580 | 0 | 0,40 | 0% |
| | | RHA-2,5 | 559 | 830 | 232 | 566 | 15 | 0,40 | 2,5% |
| | | RHA-5 | 559 | 830 | 232 | 552 | 28 | 0,40 | 5% |
| | | RHA-7,5 | 559 | 830 | 232 | 539 | 41 | 0,40 | 7,5% |
| | | RHA-10 | 559 | 830 | 232 | 526 | 54 | 0,40 | 10% |
| [9] | 2 | C30-10-100 | 763 | 1144 | 153 | 306 | 34 | 0,50 | 10% |
| | | C60-30-100 | 700 | 1050 | 150 | 350 | 150 | 0,43 | 30% |
| [10] | 3 | M0 | 692 | 1216 | 186 | 372 | 0 | 0,50 | 0% |
| | | M5 | 692 | 1216 | 186 | 353 | 19 | 0,50 | 5% |
| | | M10 | 692 | 1216 | 186 | 335 | 37 | 0,50 | 10% |
| | | M15 | 692 | 1216 | 186 | 316 | 56 | 0,50 | 15% |
| | | M20 | 692 | 1216 | 186 | 298 | 74 | 0,50 | 20% |
| [11] | 4 | MR0 | 696 | 1338 | 152 | 304 | 0 | 0,50 | 0% |
| | | MR5 | 696 | 1338 | 195 | 289 | 15 | 0,50 | 5% |
| | | MR10 | 696 | 1338 | 195 | 274 | 30 | 0,50 | 10% |
| | | MR15 | 696 | 1338 | 195 | 258 | 46 | 0,50 | 15% |
| | | MR20 | 696 | 1338 | 195 | 243 | 61 | 0,50 | 20% |
| [12] | 5 | CM | 713 | 1079 | 156 | 390 | 0 | 0,40 | 0% |
| | | M-RHA5 | 713 | 1079 | 148 | 371 | 20 | 0,40 | 5% |
| | | M-RHA10 | 713 | 1079 | 140 | 351 | 39 | 0,40 | 10% |
| | | M-RHA15 | 713 | 1079 | 133 | 332 | 59 | 0,40 | 15% |
| | | M-RHA20 | 713 | 1079 | 125 | 312 | 78 | 0,40 | 20% |
| [13] | 6 | 1. | 732 | 1112 | 160 | 400 | 0 | 0,40 | 0% |
| | | 2. | 732 | 1112 | 152 | 380 | 20 | 0,40 | 5% |
| | | 3. | 732 | 1112 | 144 | 360 | 40 | 0,40 | 10% |
| | | 4. | 732 | 1112 | 136 | 340 | 60 | 0,40 | 15% |
| | | 5. | 732 | 1112 | 128 | 320 | 80 | 0,40 | 20% |
| [14] | 7 | RHA-SDA 1 | 630 | 1260 | 189 | 315 | 0 | 0,60 | 0% |
| | | RHA-SDA 2 | 599 | 1197 | 180 | 299 | 16 | 0,60 | 5% |
| | | RHA-SDA 3 | 567 | 1134 | 170 | 284 | 32 | 0,60 | 10% |
| | | RHA-SDA 4 | 536 | 1071 | 161 | 268 | 47 | 0,60 | 15% |
| | | RHA-SDA 5 | 504 | 1008 | 151 | 252 | 63 | 0,60 | 20% |
| [15] | 8 | CC | 636 | 1113 | 166 | 474 | 0 | 0,35 | 0% |
| | | CR1 | 585 | 1113 | 166 | 447 | 27 | 0,35 | 5% |
| | | CR2 | 536 | 1113 | 166 | 420 | 54 | 0,35 | 10% |
| | | CR3 | 483 | 1113 | 166 | 391 | 81 | 0,35 | 15% |
| | | CR4 | 434 | 1113 | 166 | 366 | 108 | 0,35 | 20% |
| | | BC | 621 | 1108 | 181 | 420 | 0 | 0,43 | 0% |
| | | BR1 | 582 | 1108 | 181 | 399 | 21 | 0,43 | 5% |
| | | BR2 | 542 | 1108 | 181 | 378 | 42 | 0,43 | 10% |
| | | BR3 | 503 | 1108 | 181 | 357 | 63 | 0,43 | 15% |
| | | BR4 | 464 | 1108 | 181 | 336 | 84 | 0,43 | 20% |

| Reference | N° | ID | Aggregates [kg] | | Water [kg] | Cement [kg] | RHA [kg] | W/C | Cement replaced by RHA [%] |
|---|---|---|---|---|---|---|---|---|---|
| | | | Fine | Coarse | | | | | |
| [16] | 9 | $W_4A_0$ | 582 | 1204 | 185 | 461 | 0 | 0,40 | 0% |
| | | $W_4A_{10}$ | 582 | 1204 | 185 | 415 | 46 | 0,40 | 10% |
| | | $W_4A_{15}$ | 582 | 1204 | 185 | 392 | 69 | 0,40 | 15% |
| | | $W_5A_0$ | 608 | 1253 | 185 | 369 | 0 | 0,50 | 0% |
| | | $W_5A_{10}$ | 608 | 1253 | 185 | 332 | 37 | 0,50 | 10% |
| | | $W_5A_{15}$ | 608 | 1253 | 185 | 314 | 55 | 0,50 | 15% |
| | | $W_6A_0$ | 624 | 1288 | 185 | 308 | 0 | 0,60 | 0% |
| | | $W_6A_{10}$ | 624 | 1288 | 185 | 277 | 31 | 0,60 | 10% |
| | | $W_6A_{15}$ | 624 | 1288 | 185 | 261 | 46 | 0,60 | 15% |
| [17] | 10 | Mix 4 | 13 | 26 | 5 | 8 | 0 | 0,50 | 0% |
| | | Mix 5 | 13 | 26 | 5 | 7 | 1 | 0,50 | 10% |
| | | Mix 6 | 13 | 26 | 5 | 6 | 2 | 0,50 | 20% |
| | | Mix 7 | 13 | 26 | 5 | 5 | 2 | 0,50 | 30% |
| [18] | 11 | CM | 622 | 1184 | 152 | 399 | 0 | 0,38 | 0% |
| | | X1A | 622 | 1184 | 106 | 279 | 28 | 0,38 | 10% |
| | | X1B | 622 | 1184 | 99 | 259 | 28 | 0,38 | 10% |
| | | X1C | 622 | 1184 | 91 | 240 | 28 | 0,38 | 10% |
| [19] | 12 | B-1 | 640 | 1280 | 160 | 320 | 0 | 0,50 | 0% |
| | | B-2 | 599 | 1197 | 150 | 299 | 16 | 0,50 | 5% |
| | | B-3 | 567 | 1134 | 142 | 284 | 32 | 0,50 | 10% |
| | | B-4 | 536 | 1071 | 134 | 268 | 47 | 0,50 | 15% |
| | | B-5 | 504 | 1008 | 126 | 252 | 63 | 0,50 | 20% |
| | | B-6 | 473 | 945 | 118 | 236 | 79 | 0,50 | 25% |
| | | B-7 | 441 | 882 | 110 | 221 | 95 | 0,50 | 30% |
| [20] | 13 | CC | 640 | 1280 | 160 | 320 | 0 | 0,50 | 0% |
| | | 5 RHA | 599 | 1197 | 150 | 299 | 16 | 0,50 | 5% |
| | | 10 RHA | 567 | 1134 | 142 | 284 | 32 | 0,50 | 10% |
| | | 15 RHA | 536 | 1071 | 134 | 268 | 47 | 0,50 | 15% |
| | | 20 RHA | 504 | 1008 | 126 | 252 | 63 | 0,50 | 20% |
| | | 25 RHA | 473 | 945 | 118 | 236 | 79 | 0,50 | 25% |
| | | 30 RHA | 441 | 882 | 110 | 221 | 95 | 0,50 | 30% |

## 2.3 Test results

The compressive strength resistance has been tested after 7, 28 and 91 days. To make an effective comparison, the following graphs describe the trend of resistance over time for fixed values of the w/c ratio for the various percentages of replacement of husk ash with cement. In the following Figs 2-4 the ratio between the compressive strength with RHA, $f_{CRHA}$, and the compressive strength without RHA, $f_{C0}$, are plotted versus the percentage of RHA at 7, 28 and 91 days from curing for different w/c values. The dispersion of data is due to the fact that the tests have been done by different experimental campaigns, in fact some of them use different cement and the rice husk properties can't be always the same for all the countries: from the figures is important to analyze the behavior of the mixtures as the percentage of RHA increases.



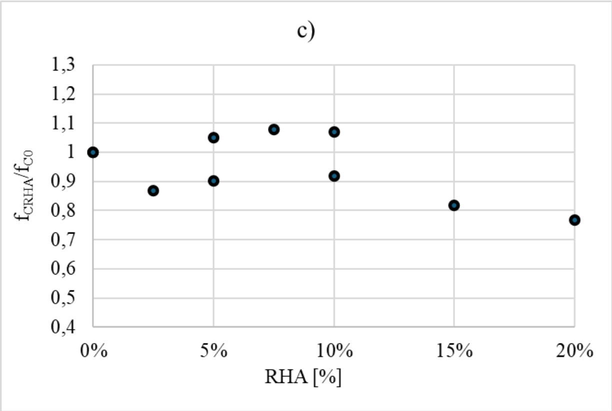



Fig. 2 Ratio between compressive strength with RHA [%] and compressive strength without RHA – w/c = 0.4 a) 7 days; b) 28 days; c) 91 days

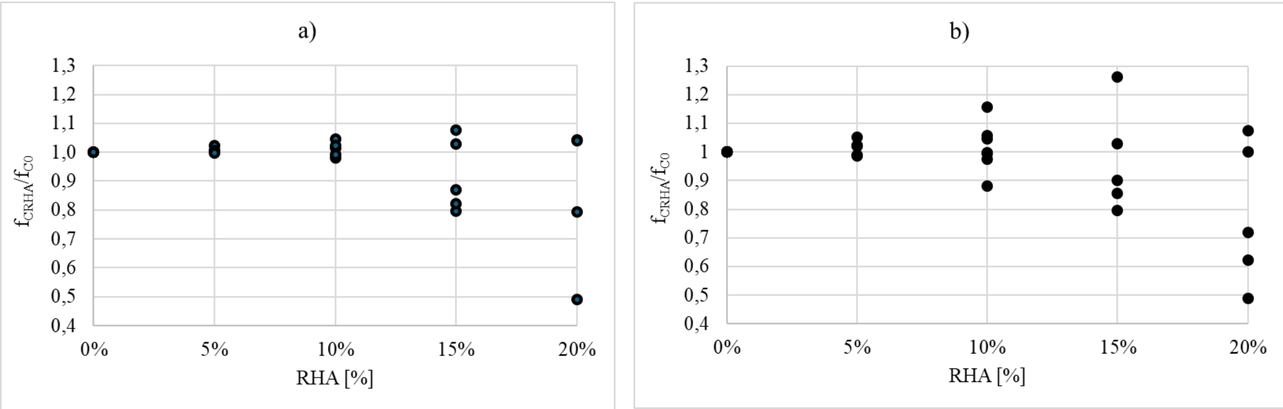
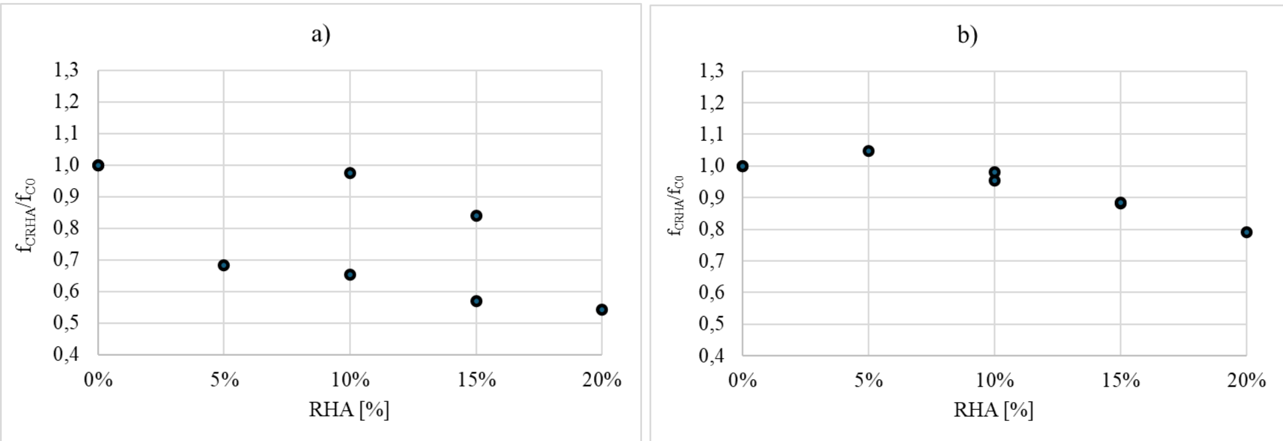



Fig. 3 Ratio between compressive strength with RHA [%] and compressive strength without RHA – w/c = 0.5 a) 7 days; b) 28 days



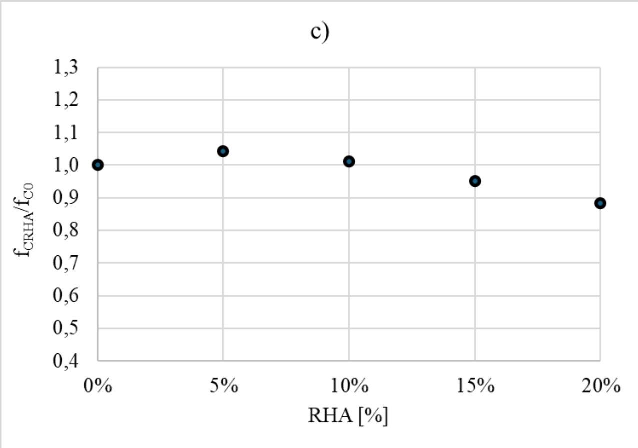



Fig. 4 Ratio between compressive strength with RHA [%] and compressive strength without RHA – w/c = 0.6 a) 7 days; b) 28 days; c) 91 days

- For the specimens with w/c = 0.4 at a maturation time of 7 days a peak is observed for a substitution equal to 5%, while at 28 days the maximum resistance is obtained with a substitution reaching 7.5%; this trend then remains constant up to 91 days, with an average resistance $f_{cm}$, greater than 50 MPa;
- For w/c = 0.5 the peak at 7 days of maturation is reached with a 10% replacement, while at 28 days the maximum strength is obtained with a 5% replacement;
- For w/c = 0.6 the behavior at 7 days does not appear to have a clearly identifiable trend, while at 28 and 91 days of maturation it is evident that the peak is reached for a substitution of 5%.

In particular at 7 days $f_{cm}$ decreases from 30 MPa for w/c = 0.4 to 15 MPa for w/c = 0.6.

- At 7 days the best performance is obtained with 5% of RHA for w/c = 0.4 and with 10% or RHA for w/c = 0.5 and for w/c = 0.6;
- At 28 days the best performance is obtained with 7,5% of RHA for w/c = 0.4, and with 5% of RHA for w/c = 0.5 and w/c = 0.6.

As told in the last paragraph, there is a great difference between some tests: this fact is due to the different type of cement used (OPC 42.5 or OPC 52.5). As can be seen in all the graphs, therefore for all values of the w/c ratio, except for the least performing case in which it is 0.6, the mixtures with a substitution percentage between 5 and 10% show better properties than those of ordinary concrete already 7 days after pouring, and then maintain a difference with respect to it that is almost constant even in the long term. In the case of the mixture with a w/c ratio of 0.6, ordinary concrete shows a higher resistance in the short term, to then be surpassed by that with a 5% substitution at 28 and 91 days. If we consider the mixtures with a substitution percentage of 15 and 20%, we observe lower initial resistances compared to the reference case (without substitution) already at 7 days (reduction between 6% for w/c = 0.35 up to 50% for w/c = 0.6), then maintaining this difference almost constant both at 28 and 91 days for the w/c ratios 0.43 and 0.5, while it tends to decrease as the water-cement ratio increases. Therefore, it can be concluded that substitution is more effective for low w/c ratios, since in cases where w/c is high, by further reducing the quantity of cement, the resistance of the material is reduced and the potential of the ash is not fully exploited. On the contrary, for a w/c equal to 0.4 the increase in resistance is maximized thanks to the substitution with husk ash in a percentage between 5 and 7.5%.

## 3 Workability

The workability test of concrete is the slump test, which is carried out in compliance with current regulations, considering the lowering of a cone of fresh concrete: five different classes are identified, of which S1 represents the minimum lowering and S5 the maximum. Only those mixtures for which no plasticizing additive has been used are taken into consideration, since it would make no sense to compare mixtures in the absence of such substances with others that contain them. In this graph the influence of the RHA replacement on the slump are compared for a) w/c = 0.4; b) w/c = 0.5; c) w/c = 0.6.

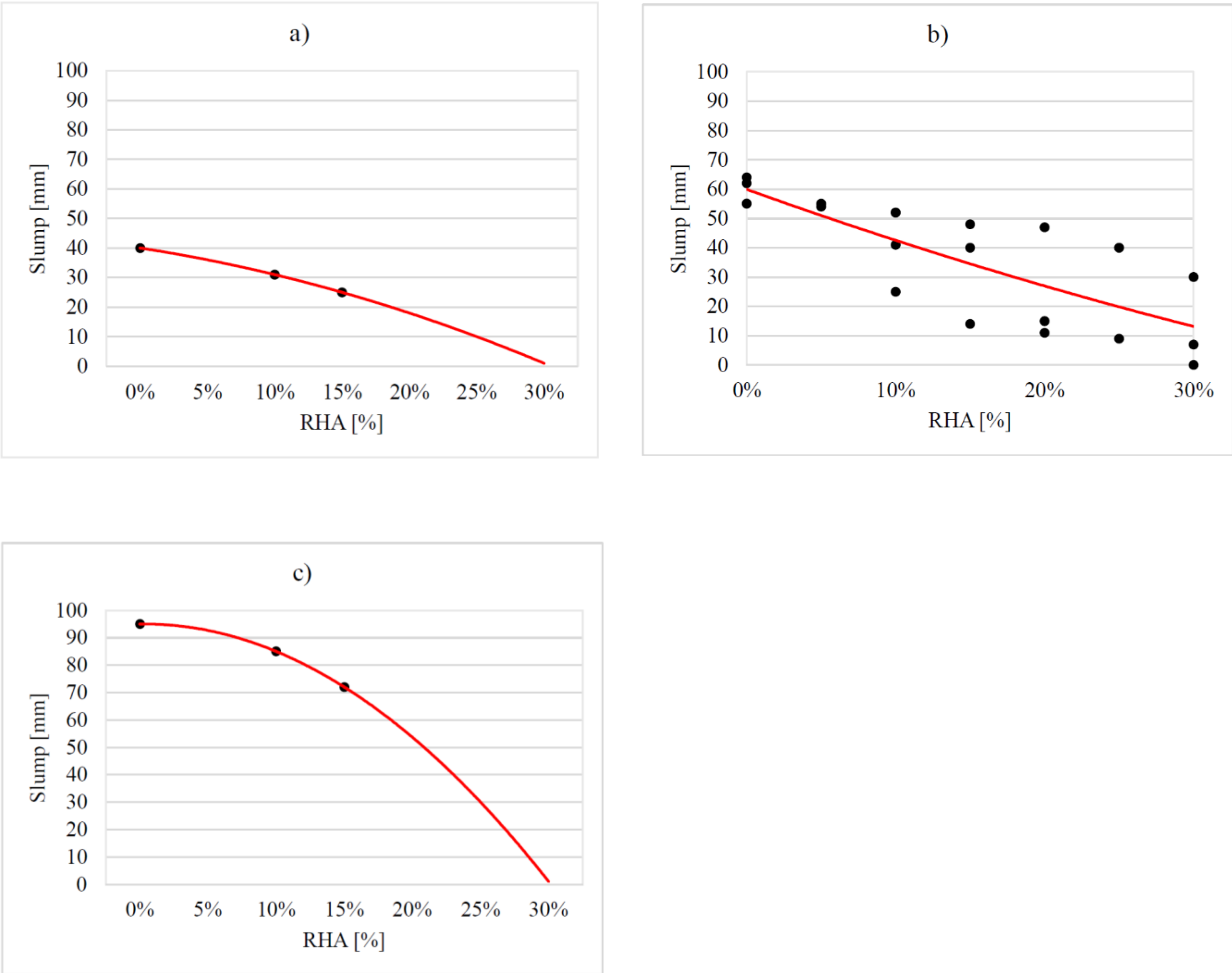



Fig. 5 Slump test in function of % RHA for a) w/c = 0.4; b) w/c = 0.5; c) w/c = 0.6

As expected, there is a general increase in slump with w/c increasing; furthermore, it is evident that as the percentage of cement replacement with RHA increases, a reduction in workability occurs. The higher the water/cement ratio, the less influence the cement replacement with RH has: this can be justified by the fact that with a higher percentage of water in the mix, this is sufficient to satisfy the ash requirement without excessively affecting fluidity. In almost all samples, it is observed that up to a 10% replacement, which corresponding to the percentage optimizing the compressive strength, the collapse in workability is rather limited, and then becomes more severe for increasing percentages. It is calculated that the optimum percentage of RHA replacement is between 5% and 10% both for resistance and workability.

## 4 Sustainability

The sustainability requirements of building materials are usually quantified on the percentage of material on total weight. In this paragraph it is proposed an index, $\beta_{CO2}$, that relates the resistance to carbon dioxide emissions. The $\beta_{CO2}$ index is obtained as the ratio between the compressive strength of the material at 28 days and the $CO_2$ emissions per unit of volume that is released for the production of the mixture. In this way, a performance coefficient was obtained, which in the future can be used as a reference parameter in the development of a "Sustainability limit state", since it takes into account both the mechanical resistance and its polluting power.

Considering the cements used in the mixtures and the materials used for the production of the concrete, the $\beta_{CO2}$ index was calculated for the three different w/c ratios previously considered (Fig. 6).

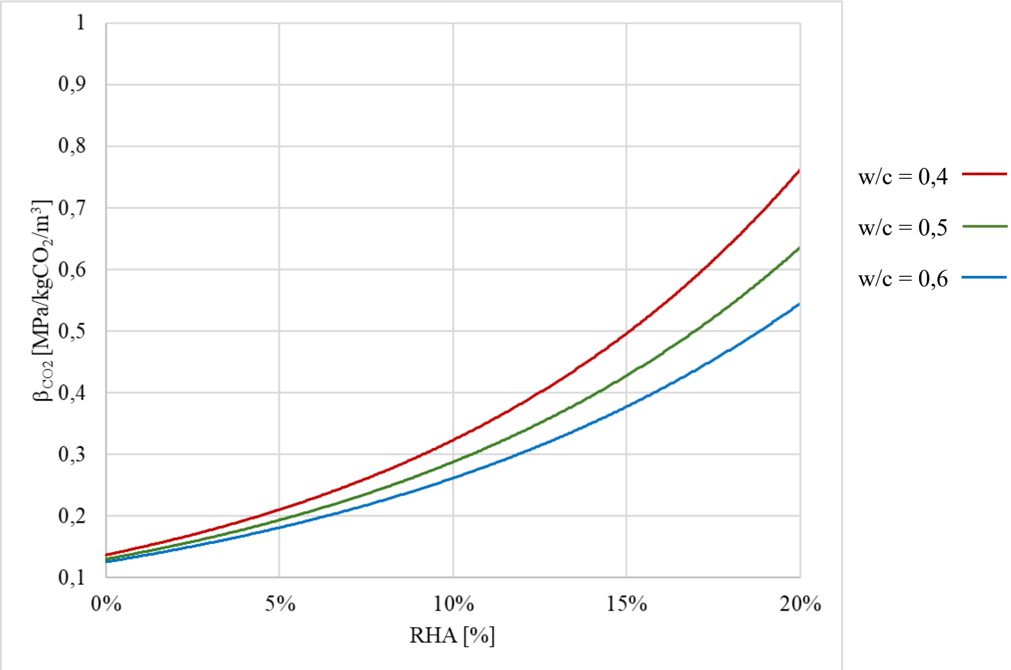



Fig. 6 $\beta_{CO2}$ in function of % RHA for w/c = 0.4; w/c = 0.5; w/c = 0.6

From Fig. 6 it is evident that as the percentage of cement replacement with RHA increases, there is an increase in the coefficient $\beta_{CO2}$ for all w/c ratios, thus producing an overall improvement in the performance of the mixture. In terms of $CO_2$ RHA has an extremely positive impact, as the carbon dioxide saved through the exploitation of combustion for heat production is greater than that released. It can be observed that, in the evaluation of the $\beta_{CO2}$ index, a mixture with poorer mechanical performance, but with a high saving in terms of carbon dioxide emissions, provides a better value.

## 5 Conclusions

Considering the very high carbon dioxide emissions associated with the construction world and the new regulations that respond to this need to make the materials used for construction more sustainable, the use of rice husk ash turns out to be an extremely advantageous choice. Through the use of a substitution percentage between 5 and 7.5% it is in fact possible to provide a new use for what would otherwise be waste. Through this addition it is possible to save on the quantity of cement in the mix without any loss in terms of mechanical performance. In this paper a performance index, $\beta_{CO2}$, has been proposed relating the resistance with the $CO_2$ emissions. By analyzing its trend, it has been evident that addition of RHA to concrete produces extremely positive results. It is in fact possible to produce heat to heat water, saving energy that would otherwise be necessary to obtain from other sources, reduce the quantity of clinker in the concrete and therefore consequently the carbon dioxide emissions associated with it, and finally increase the performance of the material itself in terms of resistance, at the cost of a modest reduction in workability, which however can be easily recovered with the use of fluidifiers.


## Acknowledgments

The authors acknowledge the support of the co-funding from the European Union through the program Interreg VI-A IT-AT 2021-2027 (project SITAR), and of Giada Zengaro for collecting the data.


## References


[1] Ricehouse. 2020. “Opportunità derivanti dai sottoprodotti del riso. Impreseedili, Produzione”. https://static.tecnichenuove.it/impresedilinews/2020/01/RiceHouse-Klimahouse-2020-1.jpg.

[2] Somma G. 2022. “Expression for calculating the compressive strength of concrete containing Rice Husk Ash”. *Current Perspectives and New Directions in Mechanics, Modelling and Design of Structural Systems – Zingoni (ed.) © 2022*.

[3] 2018. “Waste and Supplementary Cementitious Materials in Concrete”. *Woodhead Publishing Series in Civil and Structural Engineering*.

[4] Ingenio. 2020. “L’importanza Del Rapporto Acqua/Cemento Del Calcestruzzo”. Accessed February 2025. www.ingenio-web.it/articoli/l-importanza-del-rapporto-acqua-cemento-del-calcestruzzo/.

[5] Hwang C.L. Chandra S. 1997. “The use of rice husk ash in concrete”. https://www.ricehuskash.com/papers/Articles%20on%20RHA/4.The%20Use%20of%20RHA%20in%20Concrete%20220504.pdf

[6] Baston G. M. N., Clacher A. P., Heath T. G., Hunter F. M. I.; Smith V.; Swanton S. W. 2018. “Calcium silicate hydrate (C-S-H) gel dissolution and pH buffering in a cementitious near field”. *Mineralogical Magazine*. Accessed February 2025.

[7] Enco, 2018. ABC Del Calcestruzzo - H Di Hydration. Accessed February 2025. www.encosrl.it/hydration-idratazione-dei-cementi/.

[8] Patah D., Dasar A. 2022. “Strength Performance of Concrete using Rice Husk Ash as Supplementary Cementitious Materials (SCM)”. *Journal of The Civil Engineering Forum*. Accessed February 2025.

[9] He Z., Chang J., Liu C., Du S., Huang M., Chen D. 2018. “Compressive strengths of Concrete containing Rice Husk Ash without processing”. *Romanian Journal of Materials* 48 (4): 499 – 506.

[10] Chaurasia R., Malik S., Ravinder. 2022. “Study of rice husk ash on Concrete: a Review”. *International Journal of Advances in Engineering and Management (IJAEM)* Volume 4, Issue 8: 20-24.

[11] Malik I. X. 2021. “Effect of rice husk ash on compressive strength of concrete”. *Government College of Engineering Kalahandi.*

[12] Malik P. X., Singh T., Singh G. 2016. “To Study Strength Characteristics of Concrete with Rice Husk Ash”. *Indian Journal of Science and Technology* Vol 9 (47).

[13] Meena Er. P., Lata Er. N., Nagar Dr. B. 2018. “The effect of Rice Husk Ash on strenght properties of Concrete – An Experimental Study”. *International Research Journal of Engineering and Technology (IRJET)* Volume 05, Issue 09.

[14] Ettu L., Mbajiorgu U. C., Anya J. I., Nwachukwu K. C., Arimanwa J. 2013. “Strength variation of OPC-Rice Husk Ash-Saw Dust Ash composites with percentage Rice Husk Ash-Saw Dust Ash”. Accessed February 2025. https://www.researchgate.net/publication/331471340.

[15] Ramasamy V. 2011. “Compressive Strength and Durability Properties of Rice Husk Ash Concrete”. *KSCE Journal of Civil Engineering.*

[16] Siddika A., Md. Al Mamun A., Ali Md H. 2018. “Study on concrete with rice husk ash”. Innovative Infrastructure Solutions 3 (1). Accessed February 2025. https://www.researchgate.net/publication/322508279

[17] Muleya F., Muwila N., Tembo C. K., Lungu A. 2021. “Partial replacement of cement with rice husk ash in concrete production: an exploratory cost-benefit analysis for low-income communities”. *Engineering Management in Production and Services* Volume 13, Issue 3: 127-141.

[18] Shakil S. and Chalotra S. 2022. “Utilization of Silica Fume, Fly Ash, Rice Husk Ash as SCMs (A Tertiary Mix) in Plastic Aggregate Concrete”. *International Journal of Innovative Research in Engineering & Management (IJIREM)* Volume 9, Issue 4.

[19] Wagan I. H., Memon A. H., Memon N. A., Memon F. T., Lashari M. H. 2022. “Rice Husk Ash (RHA) based concrete: workability and compressive strength with different dosages and curing ages”. *Journal Of Applied Engineering Sciences* Vol. 12(25), Issue 1.

[20] Abdulazeez A. S., Yunusa U., Mohammed T. and Hamza B. 2022. “Strength Performance of Concrete Produced with Rice Husk Ash as Partial Replacement of Cement”. *African Journal of Environmental Sciences & Renewable Energy* Vol. 5, (1).

[21] Federbeton. 2022. “Rapporto di sostenibilità Federbeton 2022.” Accessed January 2025. https://blog.federbeton.it/wp-content/uploads/2023/10/Rapporto_di_Sostenibilita%CC%80_Federbeton_2022.pdf

[22] Teamobn. 2020. “How to use Rice Hulls in Gardening Effectively”: 4 Success Secrets. Accesses February 2025. https://gardens.theownerbuildernetwork.co/files/2020/01/rice-husk-background-or-texture.jpg

[23] Pula di riso. Accessed February 2025. https://img.freepik.com/foto-premium/pula-di-riso_3248-2754.jpg?%20w=996.