Budapest University of Technology and Economics
Department of Construction Materials and Technologies

SCIENTIFIC REPORT (TDK)

INVESTIGATION OF RECYCLED CONCRETE AND WASTE PERLITE POWDER AS SUPPLEMENTARY CEMENTITIOUS MATERIALS

DAVID SANTIAGO CHARRY MOTTA

RTNMN1

IV. year BSc Civil Engineering student

Supervisors:

Dr. Fenyvesi Olivèr

Associate professor

Consultant:

Dacić Amina

PhD student

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Symbols and abbreviations

C&D – construction and demolition

SCMs – supplementary cementitious materials

OPC – ordinary Portland cement

RCP – recycled concrete powder

WPP – waste perlite powder

IPCC – Intergovernmental Panel on Climate Change

1. Literature review

1.1. Introduction

As the population of humanity continues to grow and urbanization demands are higher, demolishing of old existing and construction of new structures does as well at alarming rates. Thus, a rapid increase in natural resources extraction is happening all over the world. Due to this, there is the responsibility of looking at greener and cost-effective options such as recycled aggregate concrete to decrease the carbon footprint and hazards that the construction industry can bring to the environment. Every year, it has been estimated that concrete uses about 20 billion tons of raw materials, and large amounts of old construction materials will be wasted (Kisku, et al, 2017). The construction industry, due to the demand of cement is one of the major industrial emitters of greenhouse gases, especially carbon dioxide (CO_2). The production of cement is an energy-intensive process, which represents 1 tone of CO_2 by each tone of ordinary portland cement (OPC) produced **(**Rehan, & Nehdi, 2005). In Europe, the construction industry is the biggest driver for resource consumption and waste generation, responsible for half of the resource extraction and one-third of all wastes. In European Union, the inspected Waste Framework stated that member states set the goal of achieving a 70% level of recovery for the recycling and re-use of harmless C&D (construction and demolition) waste created at construction sites by the year 2020, with most countries already exceeding the target in 2016 (Gharfalkar et al, 2015).

This research is focusing on the cementitious material, which is one of the principal ingredients that make up the concrete mixture. Cementitious materials can be categorized into two types: hydraulic cement and supplementary cementitious materials (SCMs). Hydraulic cements constitute around 20% of most concretes by volume, and their hydration products act as a binder for the aggregate. Fresh concrete qualities such as rheology, heat evolution, setting, rates of strength development, final strength, and color are influenced by cement mix and fineness, as well as other concrete ingredients (Stutzman, P., 2004). SCMs are materials that, when used in conjunction with cement contribute to the properties of hardened concrete through hydraulic and/or pozzolanic activity, SCM are designed to reduce pollution and the consumption of valuable natural resources in the concrete industry. In addition, the use of these materials generally reduces the cost and increases the durability of the concrete (Ramezanianpour, et al, 2014). This study will be taking into account recycled concrete powder (RCP), and two types of waste perlite powders (WPPs) as

SCMs. The investigation will be conducted according to different amounts used in mortar samples and the analysis of the important findings will allow us to assess possible beneficial results on the environmental impact caused by C&D waste.

1.2. Cement and its impact on the environment

Greenhouse gas emissions, particularly CO_2, are causing a global temperature rise. According to the Intergovernmental Panel on Climate Change's (IPCC) 2018 special report, we are on track to exceed a 1.5°C rise in global mean temperature compared to pre-industrial levels by 2030 at the earliest, and 2050 at the latest (Masson-Delmotte, et al, 2018). Cement is an energy-intensive product, cement alone has a production worldwide of around 4.3 billion tonnes in 2014. If current aggregate consumption rates continue, demand for aggregates is expected to double in the next two to three decades. The majority of this natural resource consumption occurs in developing countries such as China, India, and Brazil. China produces more than half of all cement, with India takes the second place with 7% of overall production of cement (**Figure 1**) (Agenda 21, the Rio Declaration on Environment and Development). Some estimations mention that concrete uses about 20 billion tonnes of raw material every year. (Kisku, et al, 2017).

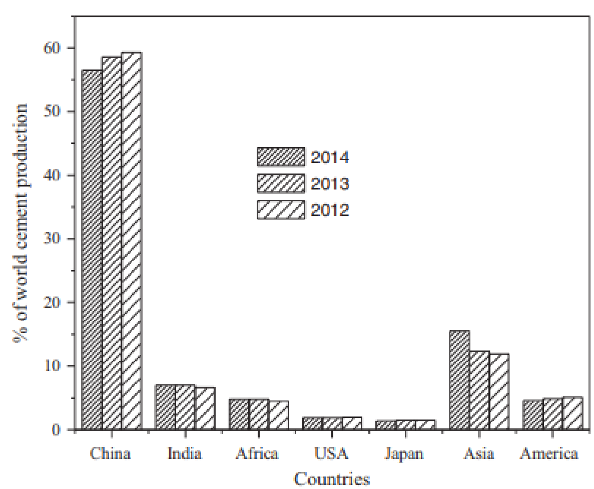

Figure 1: Major cement producers in the world (Kisku, N., Joshi, H., Ansari, M., Panda, S.K., Nayak, S. and Dutta, S.C., 2017)

Cement plants are divided into two main sources of CO_2 emissions:

- due to combustion
- due to calcination.

Combustion CO_2 emissions are linked to the fuel used in the plant. Calcination generates CO_2 when raw materials, such as limestone and clay, are placed in the furnace and heated to around 1500°C. This process liberates CO_2 to the atmosphere from the decomposed minerals.

Construction and geotechnical industries are the main users of cement. However, other emerging applications are appearing, including nuclear waste containment, dental ceramics and biological, and water filtration. Cement clinker is produced by calcining limestone (or marl or chalk) with some clay in a furnace at 1500°C and it is a significant source of greenhouse gas emissions, which are usually expressed as CO_2 equivalent (CO_{2eq}) and sometimes called "embedded carbon". Approximately 900 kg of CO_{2eq} is released per tons of cement produced by current practices (Maddalena, et al, 2018). Therefore, cement industry is estimated to contribute 5% - 7% of global anthropogenic CO_2 emissions in 2009 (Turner, et al, 2013).

The primary release of CO_2 from calcination during clinker production is responsible for 50% of the emissions from cement manufacture (**Figure 2**). The rest of the remaining emissions come from the combustion of fossil fuels for calcination, transportation, milling, plus excavation and grinding processes (Maddalena, et al, 2018).

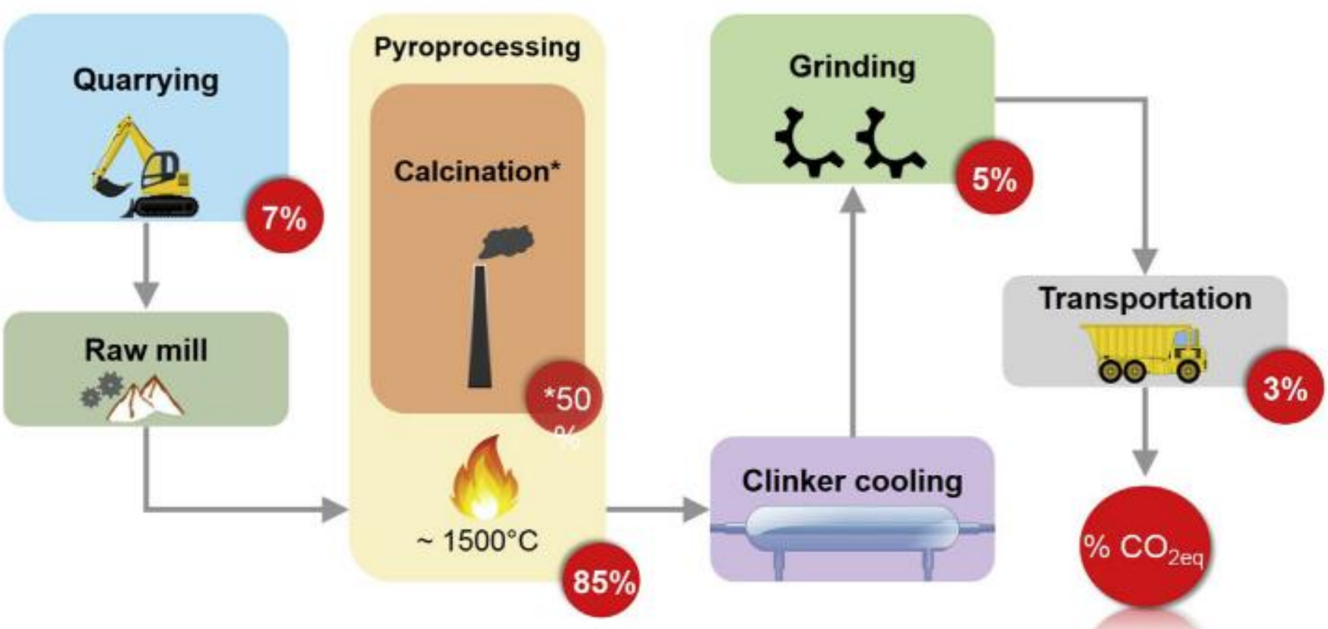

Figure 2: Simplified diagram of the cement production process (Maddalena, R., Roberts, J.J. and Hamilton, A., 2017)

1.3. Importance of recycled aggregates materials

The construction sector is the second largest emitter of CO_2, responsible for around 33% of the world's total carbon dioxide emissions. Globally speaking building emissions of greenhouse gas is about 33% and consumes roughly 40% of the global energy consumption in developed and developing countries (C. Peng & Cleaner Prod 2016). In accordance to Pataki et al. and Dimoudi et al., buildings are accountable for about 50% of total energy as well as 50% of total carbon emission in EU member countries. (D.E. Pataki, et al, 2009)

Another aspect that is harmful to the environment is the C&D waste generated in the construction industry. Rapid industrialization and urbanization have meant that old structures are increasingly being torn down and new ones built. Traditionally, these waste products would be landfilled or used in road construction. But landfill areas are becoming insufficient for the amount of C&D waste. The world demand for aggregate increases as high as 48.3 billion tons every year after 2010 and new approaches to utilize the C&D waste are becoming highly important (Kisku, et al, 2017).

Mining, processing and transportation operations used to purchase large amounts of aggregates consume significant amounts of energy, along with negative impacts on the ecology of forest areas and river beds. Therefore, an alternative to the new aggregate or SCM types has been a discussion for a long time. Over the past decades, extensive research has been conducted on recycling construction rubble so that it can replace natural aggregates and SCMs. This has emerged as utilization in alternative building materials (Kisku, et al, 2017).

1.4. Supplementary cementitious materials

The production of cement clinker and construction materials causes a significantly high amount of CO_2 emission, it is estimated that 5-8% of the annual worldwide CO_2 emission is coming from the production of cement. Due to the high demand for cement and construction materials coming from construction field, ways of mitigation of negative environmental effect started to be developed, such as modification of cement production technology, using alternative fuels, using alternative raw materials for the production of clinker and SCM s as cement/clinker replacements, development of new more environmentally friendly cements and clinkers and many more (Lothenbach, et al, 2011).

During this study, we mainly focus on the usage of the waste SCMs. We have chosen 3 different types of possible SCMs, RCP and two different types of WPP. The correct application of SCMs will allow us to understand what percentage of cement can be replaced in order to have a binder mixture able to fulfill the standards and requirements. Nowadays, SCMs are used in concrete, either in blended cements or separately in the concrete mixer. Using SCM such as blast furnace slag (a by-product of pig iron production) or fly ash (from coal combustion) is a feasible solution to partial replacement of OPC (**Figure 3**). The use of materials that do not involve an additional clinker process can lead to a significant reduction in CO_2 emissions per ton of SCMs materials. Grinding, mixing and transporting the cement consumes very little energy compared to the clinker process, which involves also fossil fuel usage at high temperatures. Additionally, this increases the utilization of by-products of industrial manufacturing processes which can reduce the environmental impact of cement production. (Lothenbach, et al, 2011)

Figure 3: Common examples of SCMs made of byproducts (waste materials) (EMS-CP, 2020)

RCP comes from C&D waste recycling process for generating recycled aggregate. It can be beneficial to use it as an SCM in the concrete mixture. Recycling plants can provide a cost saving benefit for the construction industry by recycling concrete components as well as protecting the environment. On the other hand, during the production of expanded perlite various types of waste by-product could be found. By-products found in the production of expanded perlite can be utilized in the construction industry providing an environmentally friendly solution (El Mir, et al, 2017). Perlite is a name for amorphous volcanic silicate/alumina rock and may provide a pozzolanic activity because of its high content of SiO_2 and Al_2O_3 (Rashad, 2016). Expanded perlite comes from raw material and it is applied due to its light weight. Hungary was classified to be the 5th biggest producer of perlite in 2013 (**Figure 4**). The physical and chemical properties of perlite are allowing us to introduce this material in construction and other fields. Perlite powder or expanded perlite can be used in combination with aggregate or as a material either to replace or for the addition of material in construction industry. One of the reasons why huge amounts of perlite powder are produced is because perlite is obtained in different particle sizes, therefore, large quantities of waste perlite powder are collected and stored as fine-grained waste (El Mir, et al, 2017). Erdem et al analyzed the possibility of using perlite rock as the clinker replacement up to 30%, it was found that this replacement reduces cement strength. However, it could still be used for the production of blended cement (Erdem et al 2007). Ramezanianpour et al observed that calcined perlite raw material rock enhances the durability of the concrete. Additionally, perlite powder has a significant pozzolanic effect and also improves the compressive strength of semi lightweight concrete mixtures in comparison to the control mixtures (Ramezanianpour et al 2014). In this study, the WPPs used, were produced when cutting the raw perlite rock, mainly differing in their specific surface areas.

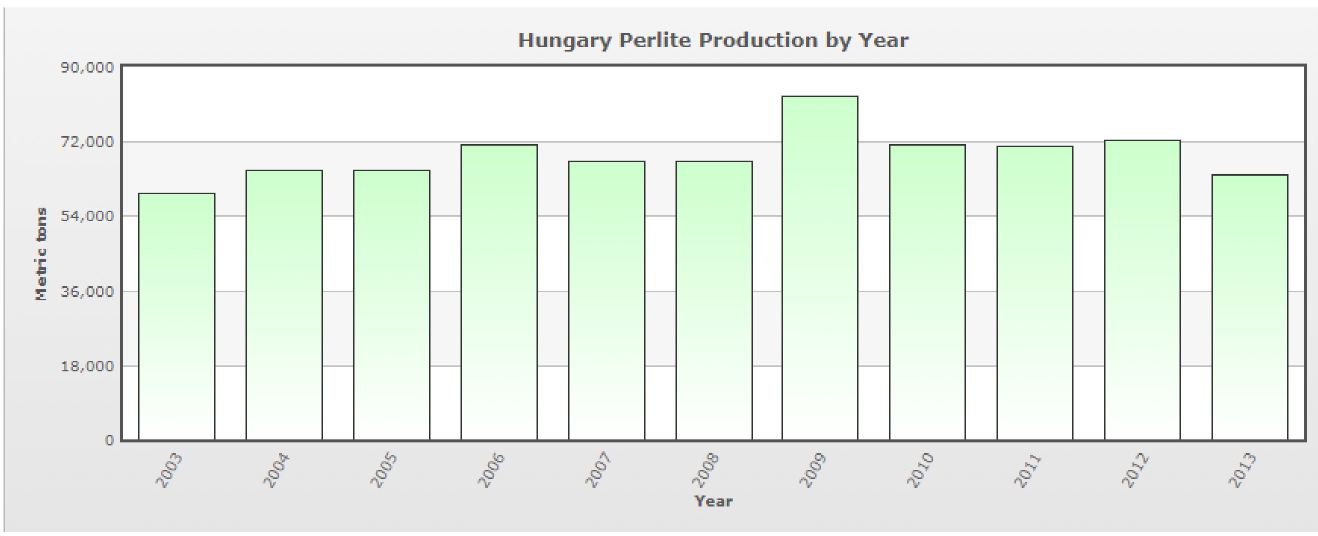

Figure 4: Hungary perlite production data from 2003 to 2013 (Index mundi, 2013)

2. Experimental investigation

2.1. Material used

The following 3 different SCMs have been used (**Figure 5**):

- Recycled concrete powder (RCP),
- Waste perlite type C (WPP-C),
- Waste perlite type (WPP-SZ).

In order to obtain the RCP, concrete blocks provided by the recycling plant were put into the jaw crusher **Figure 6**, sieved using sieving machine and categorized into coarse (4-16 mm) and fine aggregate (0-4 mm), the material passing 63µm sieve size was collected as RCP. On the other hand, OPC of class CEM I 42.5 N was used.

Figure 5: Samples of RCP, WPP-C, WPP-SZ

Figure 6: Jaw crusher

2.2. Replacement amounts of SCMs

The mixing of the samples was divided into different time intervals and ratios of SCMs in the mixture. Replacement of the cement was of 15m%, 30m%, 45m% and specimens were tested for 1, 3, 7, 28 days age. This will help us to have a better understanding of the materials behavior in different ages.

2.3. Mixing of samples

The following table shows the amounts of sand, cement, water and SCMs used for each mixture. The amounts were separated and weighted in accordance with the replacement ratio of SCMs to cement (**Table 1)**.

	References	RCP-cement			WPP-C-cement			WPP-SZ-cement		
		RCP 15%	**RCP 30%**	**RCP 45%**	**WPP-C 15%**	**WPP-C 30%**	**WPP-C 45%**	**WPP-SZ 15%**	**WPP-SZ 30%**	**WPP-SZ 45%**
cement (g)-CEM 42.5 N	450	382.5	315	247.5	382.5	315	247.5	382.5	315	247.5
standard sand (g)	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
water (g)	225	225	225	225	225	225	225	225	225	225
RCP (g)	-	67.5	135	202.5	-	-	-	-	-	-
WPP-C (g)	-	-	-	-	67.5	135	202.5	-	-	-
WPP-SZ (g)	-	-	-	-	-	-	-	67.5	135	202.5

Table 1: Amounts of the ingredients for mortar

Once the correct amounts (**Table 1**) were taken, we place them in the mixer and take note of the “zero time” (which is also taking when unmolding specimens) of the mixture. Furthermore, slump test was performed, which will be discussed in more details in the chapter 2.5. After the slump test, the molds are full by half, first half of mixture was placed in the molds and 60 impact hits were applied on the mold in order to compact the mixture, and once again till the molds are full, we repeat the 60 impact hits to compact the mixture as it is stated in the Eurocode standard (EN 196-1:2006), eventually they are weighted and stored in the climatic chamber on temperatures 20 ± 2 °C and relative humidity of 65 ± 5%

2.4. Mixer

The mixer apparatus can be seen in **Figure 7**, it consists essentially of a stainless-steel bowl with capacity of roughly 5 l, typical size and shape of it can be seen in the **Figure 8.** And a stainless-steel blade with dimension and tolerance as indicated in **Figure 8.** The revolves about its axis as it is driven in a planetary movement around the axis of the bowl at a controlled speed.

Figure 7: Mixer

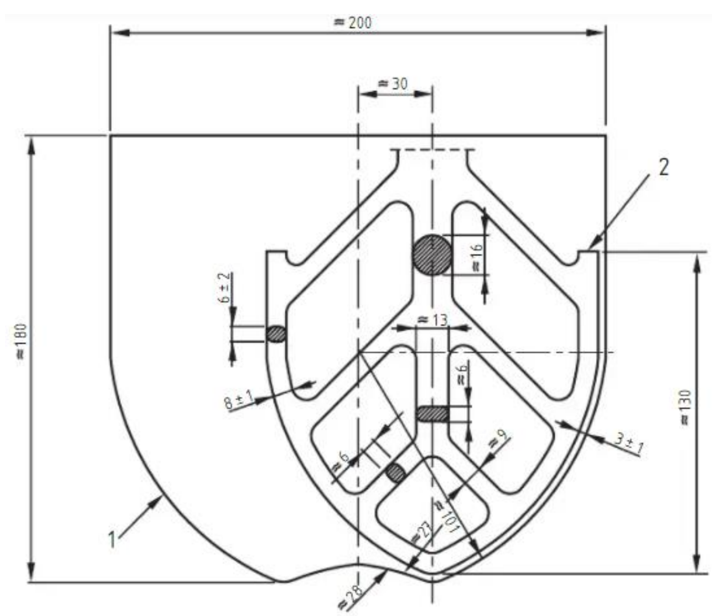

Figure 8: Typical bowl and blade, dimensions in mm (EN 196-1:2016)

The following table illustrates de speeds in which the mixer operates when it comes to mortar mixtures:

	Rotation min $^{-1}$	**Planetary movement** min $^{-1}$
Low speed	140 ± 5	62 ± 5
High speed	285 ± 10	125 ± 10

Table 2: Speeds of mixer blade according to (EN 196-1:2016)

2.5. Slump test

The slump test (**Figure 9**) is used to determine the consistency of mortar in fresh state. It's used to test the workability of freshly mixed mortar and, as a result, the ease with which it flows. During this test the consistency is determined to know how easily the mortar will flow. Not only the consistency of the mixture, but also it observes and identify defects in a mix, giving the operator a chance to enhance the mixture before pouring it on site

Figure 9: Slump test

2.6. Steps to carry out slump test

- Placed the cone on the flow table test and ensured the cone was placed firmly on it.
- Filled the cone in two layers, using the steel tamping rod 10 times to compact the mortar after each layer in an even, uniform manner.
- Once the cone is filled, removed any overflowing mortar from the top, making sure to have a smooth surface and removed any spilled mortar from the base of the cone.
- Lifted the cone vertically, using a slow and steady motion until the cone is clear of the mortar.
- Applied 15 impacts in the flow table test by rotating the handle under the flow table test, which will lift the flow table test up and drop it.
- The level of slump was measured to the nearest diameter in both directions, of the final state of the mortar after the 15 drops done with the apparatus (EN 196-1:2016).

The following pictures were taken during the slump test of our SMCs mixtures. It represents the material and the replacement ratio. E.g. RCP-15 represents Recycled concrete powder with 15% replacement ratio.

RCP -15

RCP -30

RCP -45

WPP-C -15 **WPP-C -30** **WPP-C -45**

WPP-SZ-15 **WPP-SZ -30** **WPP-SZ -45**

3. Determination of strength

During this chapter we will take a closer look in the application of the methods done in order to determine the compressive and optionally, the flexural strength of the cement mortar. The procedure is used to determine whether a cement's compressive strength meets its specifications, as well as to satisfy EN 196-1 standards.

The methods were applied in samples of 40 mm x 40 mm x 160 mm in size. The samples are cast from a mortar mixture containing one part by mass of cement, three parts by mass of CEN standard sand and one-half part of water (water/cement ratio 0.5). The mortar is mixed mechanically by the standard mixing machine and compacted in a mold with a jolting device.

The specimens are kept in the mold for 24 hours in a climate chamber before being demolded and stored under water until strength testing. Moreover, according to the specimen's required age, the specimen is taken out from their wet storage. It is broken by a flexural strength test into halves, without any harmful stresses arising in the broken pieces, and each half is tested for strength in compression (according to EN 196-1).

3.1. Guidelines in laboratory and its equipment

The laboratory where the testing and mixture of the specimens is held shall be recorded constantly, at least once per day to ensure the optimal temperature for the samples, which is 20 ± 2 °C, with a relative humidity of not less than 65 ± 5%. The storage containers for curing the specimens in water, and the grate the specimens are placed in, must be a material which does not react with cement. It is kept in a temperature of water of 20 ± 1 °C (EN 196-1).

3.2. Molds

The molds are formed with three horizontal compartments in order to form three specimens of dimensions 40 mm x 40 mm in cross sections and 160 mm in length, that can be mixed and prepared simultaneously. The following **Figure 10** shows a typical mold used to prepare three samples (EN 196-1).

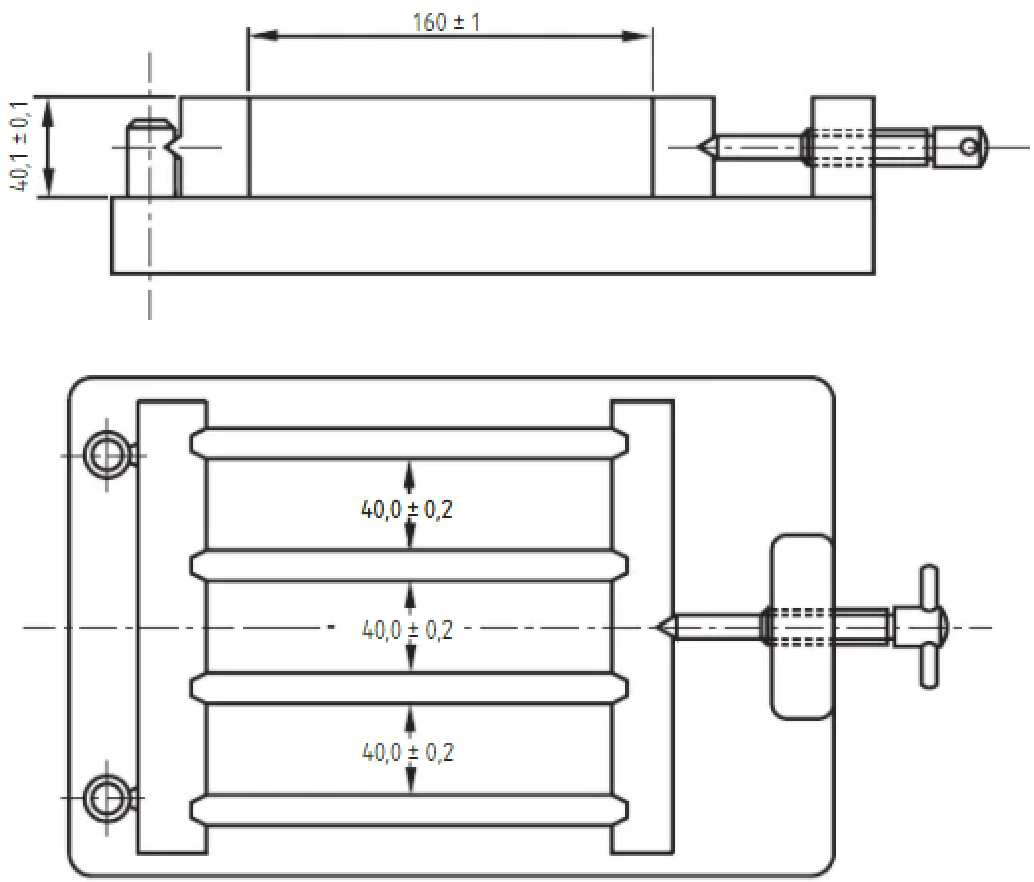

Figure 10: Typical mold (EN 196-1)

The mold needs to be designed in order to allow the samples to be unmolded without causing any harm to the specimens. Each mold comes with a steel or cast-iron baseplate. The mold shall be assembled positively and rigidly held together and fixed to its base plate. Additionally, the mold shall be such that no distortion or visible leakage, and be marked by an identification number to facilitate the assembly and to keep track of samples mixed. The interior dimensions and tolerances of each mold compartment must be as follows:

- length: (160 ± 1) mm,
- width: (40,0 ± 0,2) mm,
- depth: (40,1 ± 0,1) mm.

The flatness, perpendicularity tolerance is not greater than 0.03 mm, 0.2 mm respectively and surface texture tolerance according to ISO 1101, EN ISO 1302.

3.3. Compaction procedure using vibrating tables

This device (**Figure 11**) is used to compact the mixture into the molds, it could be found in different designs. The device has a metal table where the mold can be placed. The apparatus shall be fixed to the ground, by anchor or bolts to ensure vibration free contact.

In operation, the table is raised by a cam and allowed to fall freely from a height of 15,0 ± 0,3 mm before the metal table strikes the stop. The device is operated by an electric motor with uniform speed. A control mechanism and a counter shall be provided to ensure that one period of jolting of includes exactly 60 jolts (60 ± 3).

Figure 11: Compaction table

3.4. Demolding of specimens

The demolding needs to be carried out with care in order to avoid any damage in the specimens. Plastic or rubber hammers are for demolding. Carry out demolding for the tests at different ages (EN 196-1).

3.5. Curing

Submerged the specimens in a convenient manner, horizontally or vertically, in water at 20.0±1.0°C in the containers. Make sure to keep them apart from each other in order to let water has access to all six faces of the specimens. Place specimens on a grate (EN 196-1).

4. Flexural tensile strength testing apparatus

Flexural tensile strength can be measured using a flexural tensile strength testing machine or a compression testing machine using a suitable device. In any case, the device must meet the following requirements:

The device for determining flexural tensile strength needs to be capable of applying loads up to 10 kN with an accuracy of ± 1.0% and at a load rate of 50 ± 10 N/s.

The device is equipped with a bending device that includes two steel support rollers with a diameter of 10.0 ± 0.5) mm at a distance of 100.0 ± 0.5 mm and a third steel load roller located on the center between the other two. The length of these rolls should be between 45 mm and 50 mm. The loading arrangement is shown in **Figure 12 (**EN 196**)**.

The three vertical planes through the axes of the three rollers must be parallel and remain parallel in equal distance. One of the supporting rollers and the loading roller must be capable of tilting slightly if required, to allow a uniform distribution of the load over the width of the specimen without applying any torsional stresses.

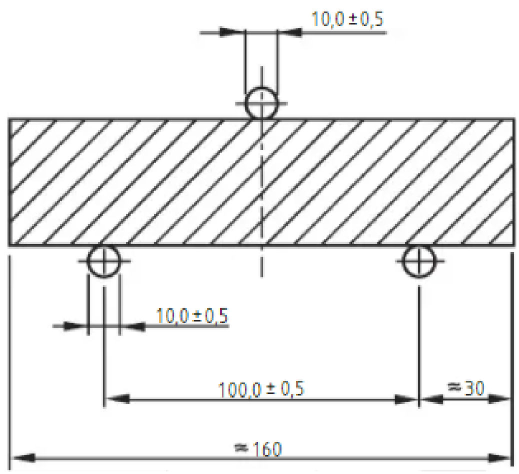

Figure 12: Front-view of flexural tensile device

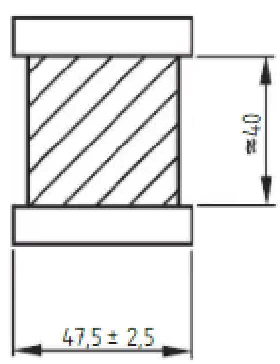

Figure 13: Side view of flexural tensile device

Figure 14: Flexural tensile and compression device

Figure 15: Flexural tensile device

5. Compressive strength testing machine

This machine (**Figure 16**) should have an accuracy of ± 1.0%, it should provide a rate of load increase of 2 400 ± 200 N/s. The machine also indicates the maximum stress at failure of the specimens, and the maximum load till failure should remain indicated after the testing machine is unloaded.

The machine has and upper and lower plate where the specimen is placed align with the plates. The resultant of the forces must pass through the center of the sample. The surface of the bottom platen of the machine must be perpendicular to the axis of the machine and remain in such a way during loading. Additionally, the upper plate must be able to align freely when it comes into contact with the sample, but the relative position of the upper and lower clamp plate must remain fixed during loading

Figure 16: Compressive strength machine

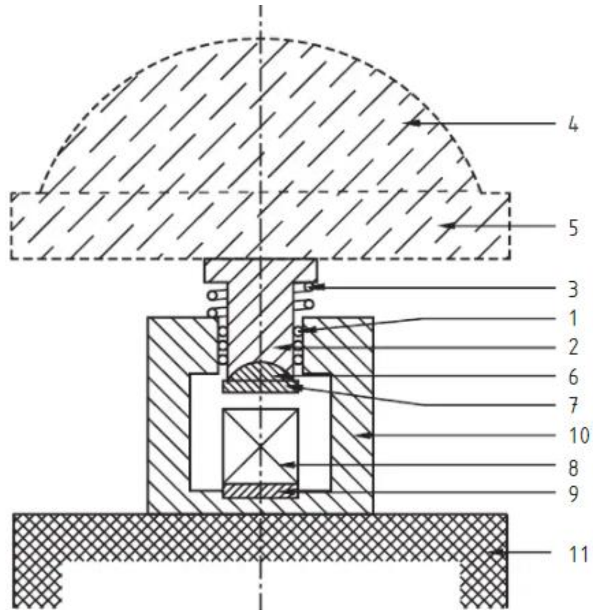

Figure 17: Compressive strength machine (EN 196)

Figure 16: Compressive strength machine

Name of compressive strength machine parts:

1. Ball bearings
2. Sliding assemble
3. Return spring
4. Spherical seating of machine
5. Upper platen of machine
6. Spherical seating of the jig
7. Upper platen of the jig
8. Specimen
9. Lower platen of the jig
10. Jig
11. Lower platen of the machine

6. Flexural tensile strength

By using the apparatus described in chapter 4. Placed the specimens in the machine with one side face on the supports and making sure its longitudinal axis normal to the supports. Applied the load on it by the loading roller which is located on the opposite side face of the supports and increase it gently at a rate of 50 ± 10 N/s until failure of the specimen (EN 196-1). Moreover, collect the halves of specimens for the compression test.

In order to calculate the flexural strength R_f, the following equation is used:

$$R_f = \frac{1.5 \times F_f \times l}{b \times d^2}$$

Where:

R_f is the flexural strength, in megapascals;

F_f is the load applied to the middle of the specimen at fracture, in newtons;

b is the width of the square section of the specimens, in millimeters;

d is the height of the square section of the specimens, in millimeters;

l is the distance between the supports, in millimeters.

7. Compressive strength

The test is carried out with the 2 halves left after the flexural tensile test. The test is carried out by placing the halves in the machine described in chapter 5 and loading its side faces. Therefore, we center the specimens' halves laterally to the platens of the machine within ± 0.5 mm, and longitudinally in a way that the end face of the specimen overhangs the plates by about 10 mm (EN 196-1 standards).

The load shall be increase gently at a rate of 2 400 ± 200 N/s over the whole load application until the fracture of the specimen (EN 196-1 standards).

In order to calculate the flexural strength R_c, the following equation is used:

$$R_c = \frac{F_c}{A}$$

Where:

R_c is the compressive strength, in megapascals;

F_c is the maximum load at fracture, in newtons;

A is the area of the plates or auxiliary plates 40 mm x 40 mm, in square millimeters.

8. Results of flexural tensile test

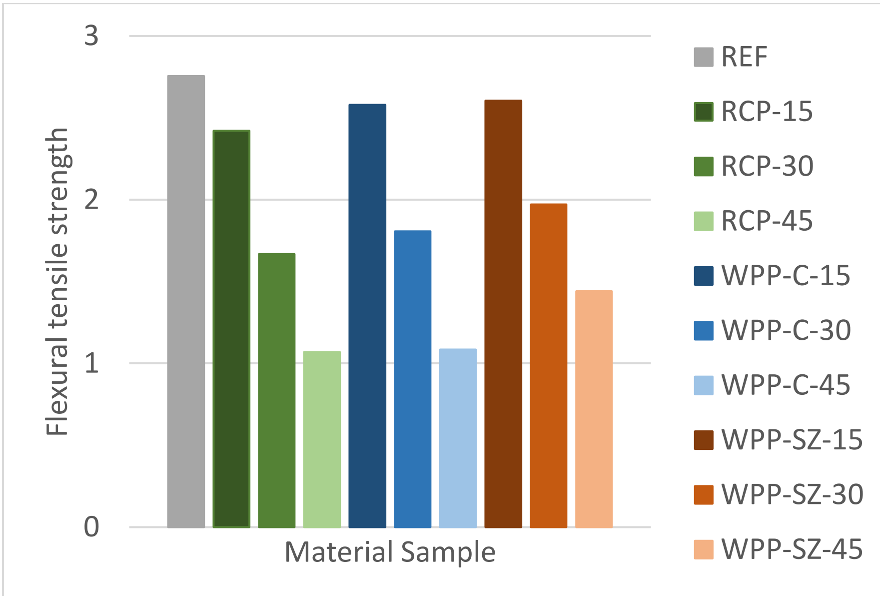

Diagram 1: Flexural tensile strength – 1 day 5/10/2021

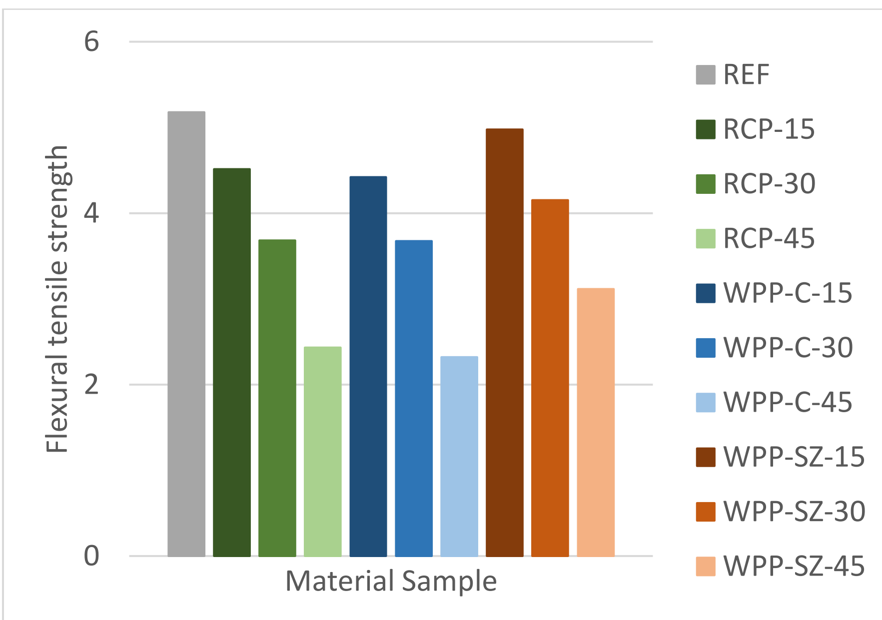

Diagram 2: Flexural tensile strength – 3 days 23/9/2021

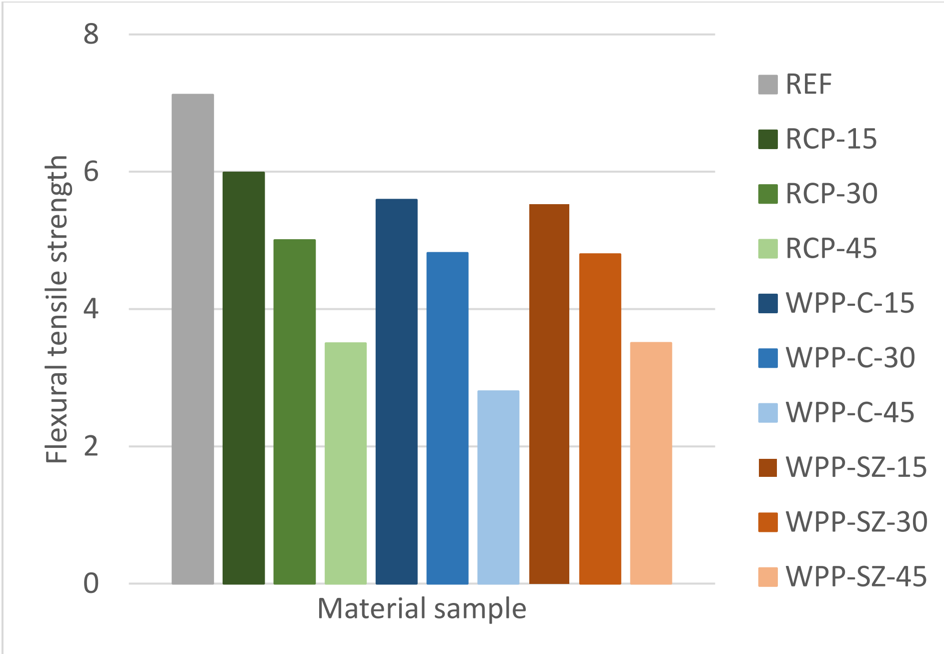

Diagram 3: Flexural tensile strength – 7 days 20/9/2021

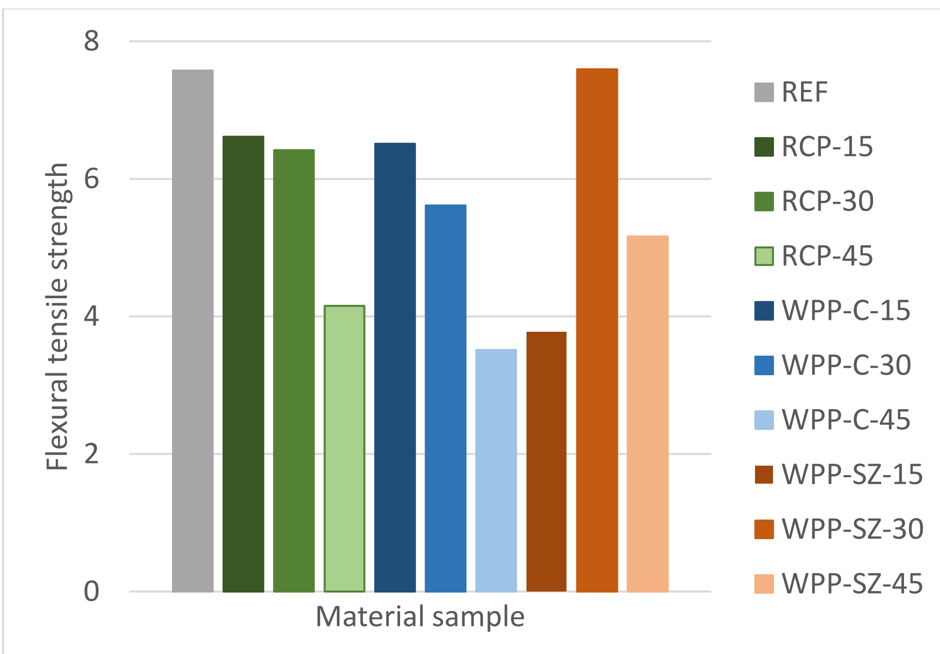

Diagram 4: Flexural tensile strength – 28 days 8/10/2021

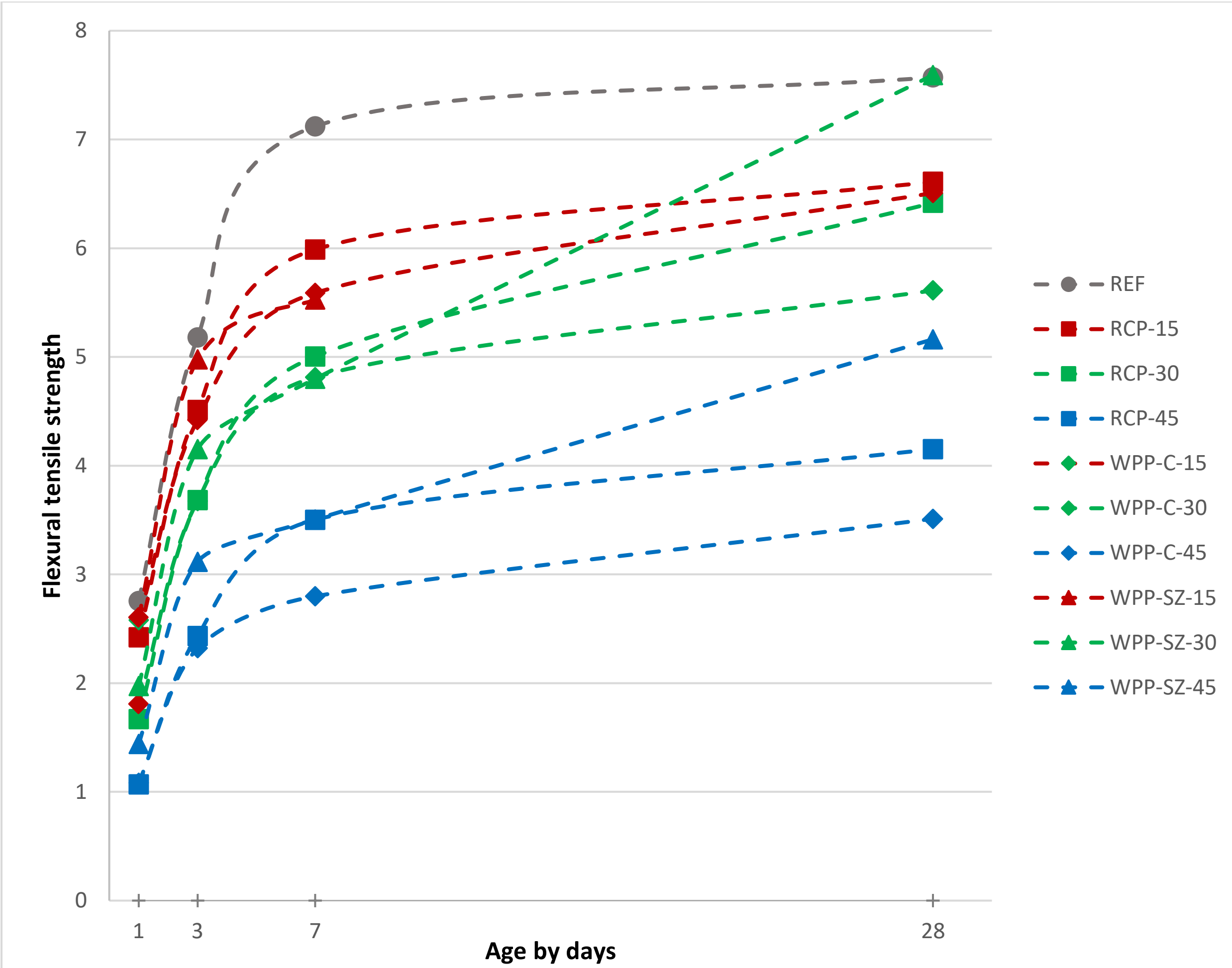

Diagram 5: Flexural tensile strength comparison at all ages of the specimens

In **Diagram 5** it was observed that the comparison of all the specimens of RCP, WPP-C, WPP-SZ with 15%, 30%, 45% replacement ratio and at ages of 1, 3, 7, 28.

Based on the diagram all of the specimen's strength are increasing by the age. It can be observed that WPP-SZ reach same strength as the reference by the 28 days age. It can also be observed that for most of the cases WPP-SZ samples are having higher strength at 28 days age.

9. Results of compression test

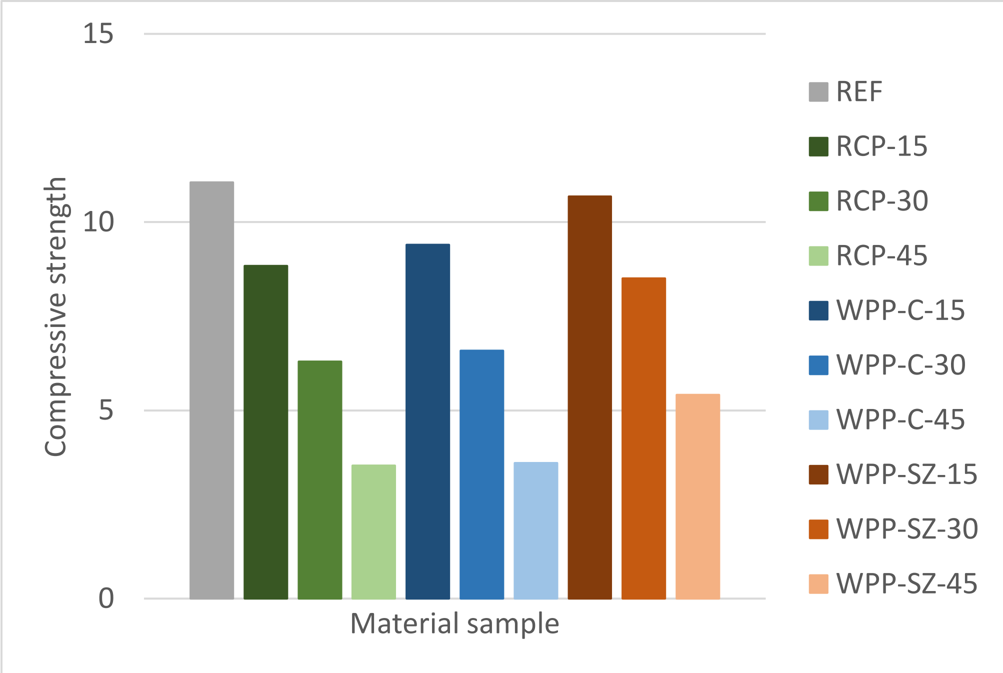

Diagram 6: Compressive strength – 1 day 5/10/2021

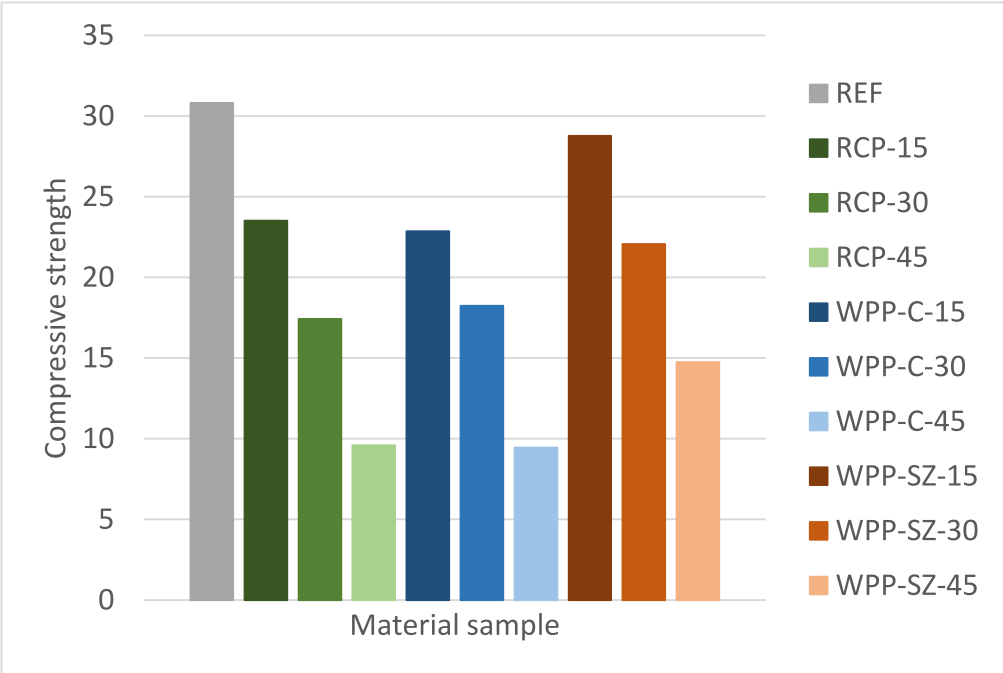

Diagram 7: Compressive strength – 3 days 23/9/2021

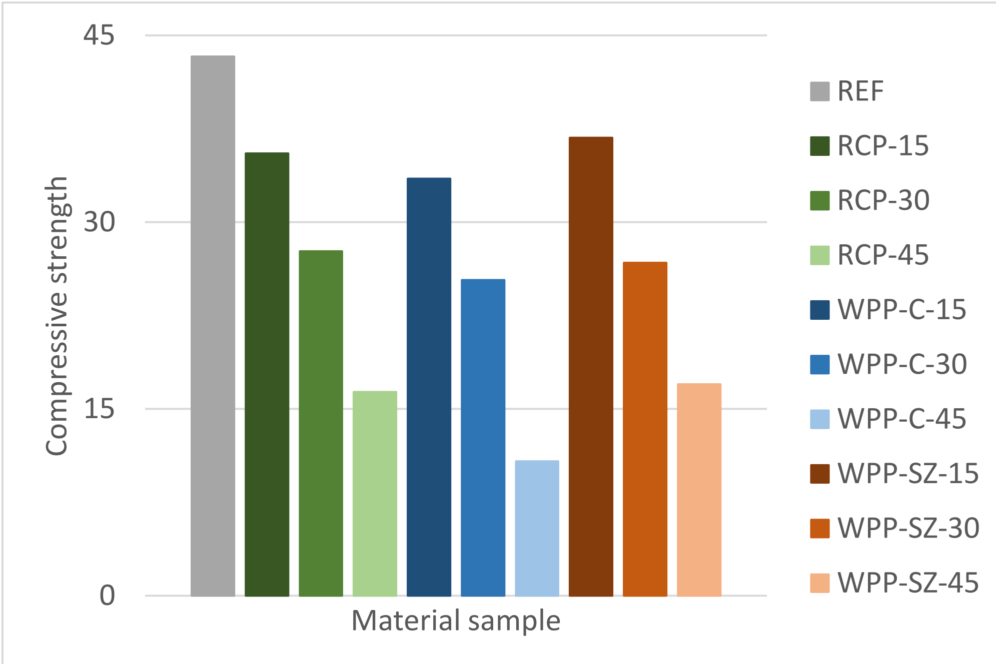

Diagram 8: Compressive strength – 7 days 20/9/2021

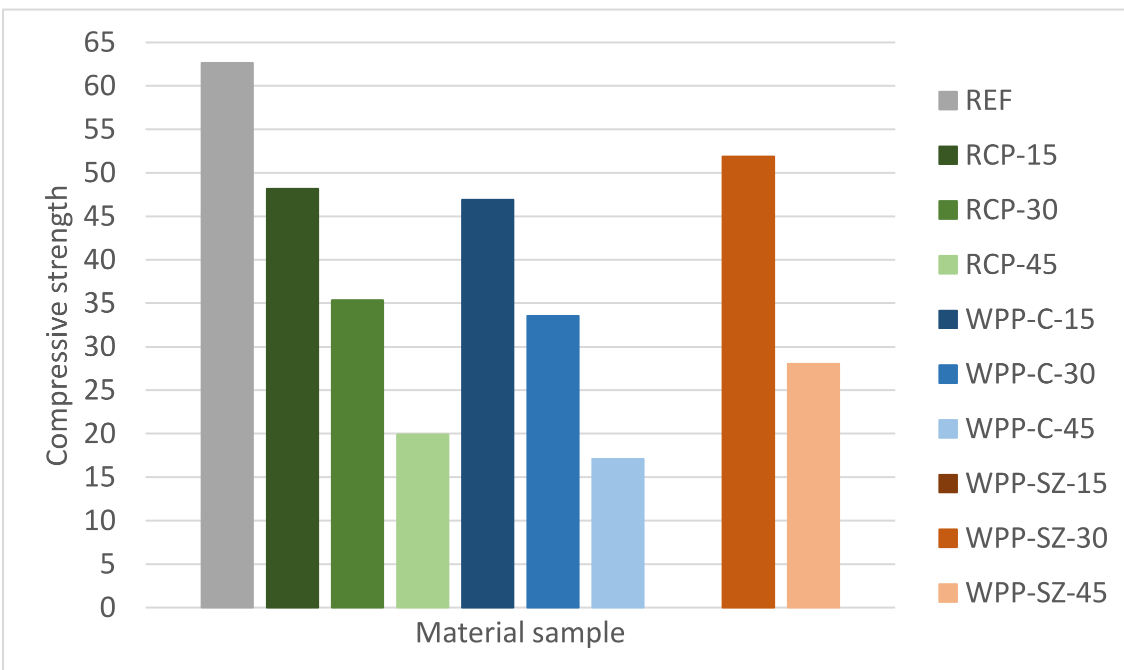

Diagram 9: Compressive strength – 28 days 8/10/2021

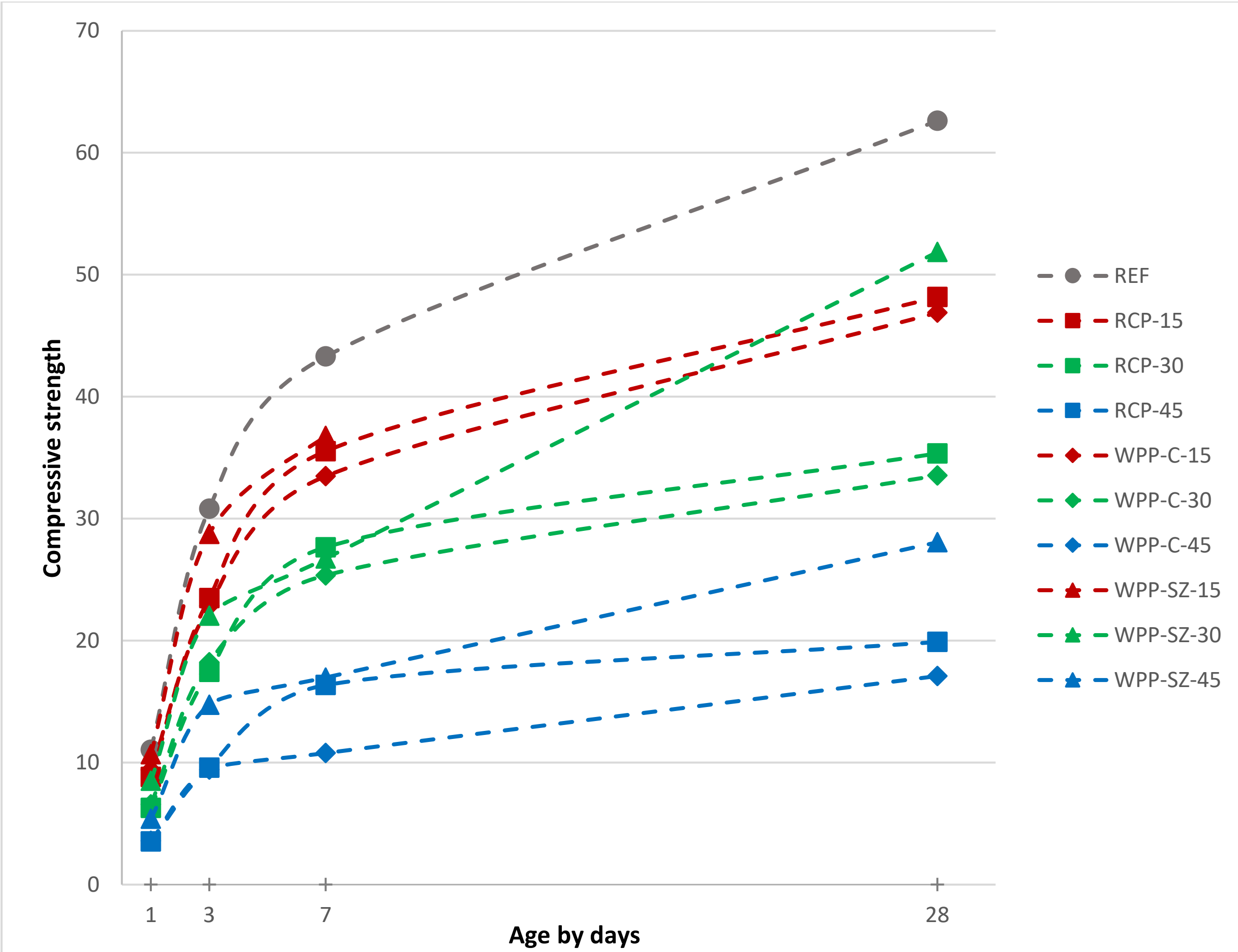

Diagram 10: Compression strength comparison at all ages of the specimens

The **Diagram 10** shows the comparison of all the specimens of RCP, WPP-C, WPP-SZ with 15%, 30%, 45% replacement ratio and at ages of 1, 3, 7, 28, for compression strength.

The results of the graph displayed an increase in the strength by age. It also shows that the material WPP-SZ with 30% ratio replacement has the highest strength among the other SCMs by the 28 days age. However, none of the SCMs reach or pass the reference compression strength. Additionally, RCP material is having higher strength compared to the WPP-C at most of ages. On the other hand, even though WPP-SZ specimens have higher strength in compression compared to RCP and WPP-C specimens, it does not reach the reference compression strength, in fact, the compression strength decreased by 17.18% from the compression strength reference to the WPP-SZ-30. Moreover, RCP has a decreased in compression strength compared to WPP-C by 5.120% with a 30% replacement ratio of SCM at 28 days age

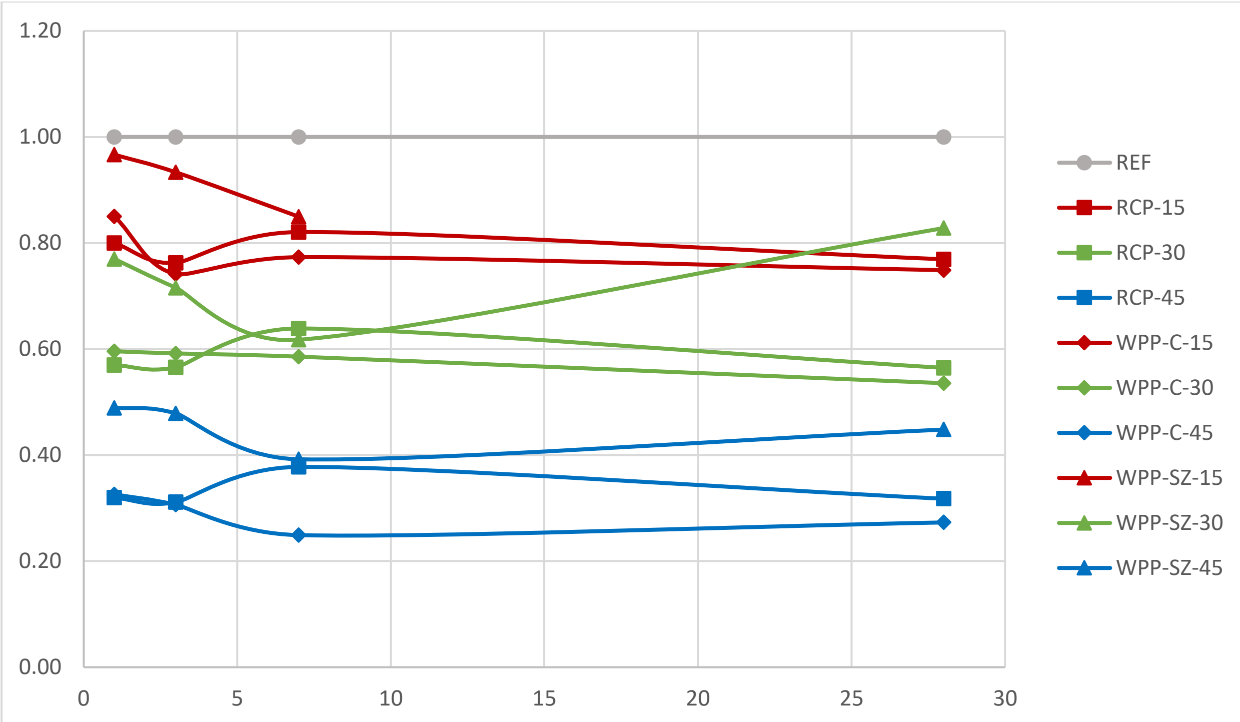

Diagram 11: Strength activity index

Diagram 11 represents the ratio of the strength over the strength of the reference specimen. It is observed that with the age the strength does not increase or decrease significantly, because of the low pozzolanic activity. Additionally, we will evaluate the results to investigate the material used as a filler.

At 28 days age it does not show high pozzolanic activity according to the strength activity index. For instance, in case of WPP-C-15 it can observed that the result is not consistent. Above 30% replacement ratio it reduces the pozzolanic activity. However, in case of WPP-SZ-30, the diagram indicates higher value at 28 days age compared to the other SMCs, but in case of 45 replacement ratio it does not increase significantly. Moreover, the diagram shows that WPP-C always has lower strength activity index, it may be for its chemical properties and specific surface area. The 45% replacement ratio seems to be too high as it decreases the strength parameters by high rate.

10. Fresh density

In the result of the fresh density, it is decreasing in all of the specimens by increasing of the SCMs dosage. Typically, it is higher when having higher replacement ratios. Another factor that can influence to the fresh density is the specific surface area, we expect that it has the higher specific surface area. WPP-SZ is having higher fresh density compared to the RCP because the higher specific surface area. In the following table we can see the average of the fresh density in 1, 3, 7, 28 days age for all the SMCs materials used and the reference sample.

Sample	ρ_s (kg/m^3) Averages
REF	2,305.73
RCP-15	2,264.84
RCP-30	2,225.00
RCP-45	2,196.61
WPP-C-15	2,256.25
WPP-C-30	2,220.57
WPP-C-45	2,184.90
WPP-SZ-15	2,280.47
WPP-SZ-30	2,246.88
WPP-SZ-45	2,219.79

Table 3: Average fresh density

11. Slump test

As it can be seen the references sample has the highest slump. Moreover, the slump test decreases with higher replacement ratios as shown in the average values from each specimen because the SCMs used are expected to have higher specific surface than the applied cement. Photographs taken during the slump test can be found in Chapter 2.5.

Sample	Average (cm)
REF	15.0
RCP-15	14.9
RCP-30	13.8
RCP-45	12.3
WPP-C-15	14.4
WPP-C-30	13.8
WPP-C-45	12.4
WPP-SZ-15	14.0
WPP-SZ-30	12.8
WPP-SZ-45	11.2

Table 4: Average slump test results

12. Conclusions

The goal of this research paper was to identify the behavior in strength of mortar samples, when replacing the amount of cement with different amounts of SCMs. Taking into account the big demand for construction materials, such as cement and materials that go to waste and can be reused as a greener solution in the construction industry, we have used recycled materials like concrete and waste perlite. During the experiments, we could determine the different strengths of mortar mixtures according to the different ratios of SCMs and age of the specimens. The samples tested have shown variation in their strengths compared to the others and the reference specimen.

WPP-SZ-30, which represents waste perlite material with a replacement ratio of 30%, proved to have the highest flexural tensile strength compared to the rest of specimens. Generally, the specimens were having an increase in flexural tensile strength by the age. Higher strengths were found in specimens with 30% replacement ratio of SCMs.

Additionally, regarding compression strength of samples, WPP-SZ-30 shows the highest strength compared to the RCP and WPP-C with 15%, 30% and 45% replacement ratio. Nonetheless, the compressive strength of WPP-SZ-30 decreased by 17.18%, compared to the reference compressive strength. The physical properties, such as specific surface area, density and chemical properties, as well as grading of the powders will be investigated in order to evaluate their effect on the specimens.

The test results displayed the fact that, the mixtures involving RCP usable cementitious materials can be used and mixed for construction applications. Some more conclusions were drawn as following:

- The RCP can be applied as a fine aggregate powder in concrete and other cementitious materials.
- In the next research phase, we will investigate the hydraulic activity of RCPs and WPP powders, whether they have hydraulic behaviors or not and how it could influence the mixture.

- WPP-SZ has better behavior than RCP, as it has hydraulic activity, so it can be applied as SCM. Therefore, we could use a waste material in order to mitigate the amount of CO_2 emissions of cement production.
- WPP-C-15, WPP-C-30, WPP-C-45 has the lowest compressive strength by 28 days age compared to the RCP and WPP-SZ.
- An increase of long-term strength was observed in the mortar samples due to the SCMs.
- The SCMs, such as WWP-SZ and RCP can be reused for new mixtures according to its requirements, which will lead to less wasted material.
- The higher the replacement ratio, the less workability in the freshly made mixture was detected, which could cause problems in the mixture flow and uniformity of the mixture.

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