

Cementitious Material of Marble Waste Industry as Alternative Approach to Sustainable Concrete

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Informasi Artikel

Riwayat Artikel

Diserahkan : 17-06-2023

Direvisi : 28-06-2023

Diterima : 29-06-2023

Kata Kunci:

Komposisi mineral; Serbuk marmer; Sifat mekanik beton

Keywords:

Mineral content; Marble dust; Mechanical properties of concrete

ABSTRAK

Untuk mengurangi dampak emisi karbon akibat produksi semen diperlukan material alternatif untuk mengurangi penggunaan semen pada beton. Serbuk marmer merupakan limbah industri marmer merupakan bahan mineral yang dapat dimanfaatkan untuk mengurangi jumlah semen pada beton. Metode X-Ray Fluorescence (X-RF) dilakukan untuk mengetahui komposisi mineral serbuk marmer. Hasil penelitian menunjukkan bahwa serbuk marmer terdiri dari mineral CaO 98,62%, Sulfur Trioksida (SO₃) 0,17%, dan mineral lainnya. Penelitian ini bertujuan mengetahui bagaimana pengaruh serbuk marmer terhadap sifat mekanik beton. Benda uji dibuat dalam empat variasi berdasarkan penggunaan serbuk marmer sebagai bahan pengisi beton, yaitu 0%, 5%, 10%, dan 15%. Pengujian memberikan hasil penggunaan serbuk marmer optimum adalah 6,62% dengan kuat tekan beton meningkat sebesar 11,77%.

ABSTRACT

Concrete needs to use alternative materials to reduce cement content to limit the effect of carbon emissions. Marble dust as a waste of the marble industry has very fine grains. X-Ray Fluorescence (X-RF) method was conducted to determine the mineral properties of marble dust. Marble dust was found to contain 98.62% Calcium Oxide (CaO), 0.17% Sulfur Trioxide (SO₃) and some elements in small levels. To determine the impact of marble dust on the mechanical characteristics of concrete, an experimental study was conducted. Test specimens were made with four different levels of marble dust, namely 0%, 5%, 10%, and 15%. The experimental results showed that the optimum usage was 6.62% by weight of cement which gave the advantage of increasing the compressive strength of concrete by 11.77%.

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INTRODUCTION

The worldwide cement production, estimated at around 4500 million tons per year, generates large amounts of CO₂ emissions that contribute to climate change (Kajaste & Hurme, 2016). The calcination process in cement manufacturing produces enormous amounts of CO₂ (Thakur et al., 2018). CO₂ emitted by the cement industry globally has tripled since 1992. Cement manufacturing is now responsible for 4.1 billion metric tons of annual carbon emissions, which

has grown by 9.3% from 2015 to 2020 and is projected to increase to 5.8 billion tons by 2050 (Hira et al., 2016). The increasing concrete-based building sector is in line with the high production of cement. In order to manage global climate change, it is necessary to limit the use of cement in concrete and produce sustainable building materials in accordance with the Sustainable Development Goals (SDGs) to ensure sustainable consumption and production patterns.

The mining and processing of marble in Indonesia are spread over several islands. Tulungagung is one of the oldest and largest marble-producing areas in Indonesia. The largest marble mining activity is carried out by PT. Industri Marmer Indonesia Tulungagung with a mining area of 5.93 hectares and a production of 9.9 million tonnes/per year. Additionally, around 150 small and medium business units are engaged in processing marble with production reaching 2,250 tons/day (BPS Kabupaten Tulungagung, 2022). Marble processing activities produce waste in the form of marble fragments and water mixed with marble dust which is shaped like slurry, with an amount of about 50% of the final product of the marble industry (Tressmann et al., 2020). Processing marble in large quantities and continuously causes problems in the amount of waste produced. The waste collection system on open land around the processing site is less effective and pays less attention to land conservation. Therefore, there is a need for a solution to solve this waste problem.

In order to reduce the use of cement in concrete, research has been conducted into the possibility of using marble dust as a pozzolanic mineral. According to the research, marble dust can increase the compressive strength of concrete by 50%; however, as the composition of marble dust increases, the compressive strength of concrete decreases (Oza et al., 2022). When used as a partial replacement for cement in concrete, marble dust increased the compressive strength by 17.7% after 28 days. This increase was achieved by exchanging 10% of the cement by weight with marble dust. The strength of the concrete increased progressively with the addition of marble dust, but then gradually decreased (Shelke et al., 2014). Waste pozzolan is used because it can be used more cheaply and because it will make the concrete asset more durable. The environmental effects of waste will be lower due to improvements in concrete manufacturing that will consume less energy and natural resources (Shukla et al., 2019). The behaviour of concrete will usually be affected by mineral inclusions. Therefore, observations were made on concrete mixtures using different weight amounts of cement replacement and marble dust as fillers (Aliabdo et al., 2014).

Observations on the physical and mineral properties of marble dust were made to determine the possibility of utilizing marble dust in concrete and to determine the effect of using marble dust as a pozzolanic mineral in concrete on the behaviour of fresh concrete and the mechanical properties of concrete. The effect of using marble dust on the properties of fresh concrete was observed and the mechanical properties were tested at 28 days of age. This research is expected to provide a solution for handling waste problems in the marble industry area. Finding materials that will reduce the use of cement in concrete. The prospect of lowering CO₂ emissions generated during cement manufacture is an important environmental objective of the suggested technology.

METHOD

The marble dust used in this study came from Tulungagung Regency, East Java, Indonesia. Testing of the physical properties of marble dust, including weight loss, grain size and specific gravity, was conducted in the laboratory to identify the marble dust waste samples. XRF analysis was conducted to determine the composition and concentration of minerals contained in the waste samples.

To investigate the use of marble dust waste in concrete, concrete mixes were made with a desired concrete compressive strength of 20 Mpa at a w/c ratio of 0.5 and a concrete mix design based on the Indonesian National Standard (BSN, 2012). The specimens were cylindrical with a height of 300 mm and a diameter of 150 mm. The mixture was made in 4 types of specimens with variations in the use of marble powder 0%, 5%, 10%, and 15% by weight of cement with a cement water factor of 0.5 for all specimens. Each specimen was made into 5 pieces. The average value of

the specimens was used in this analysis. To obtain the planned compressive strength values, the specimens were immersed for curing of the concrete to maintain the moisture content of the concrete at a suitable temperature to support the hydration of the cement in the early period. The mechanical properties of concrete were tested at 28 days of concrete age. Testing the compressive strength of concrete is done by applying a load until the specimen is crushed (ASTM, 2021). The modulus of elasticity and Poisson's ratio tests were performed by measuring the longitudinal and transverse strains of the specimens at 40% of the maximum load. The testing procedures for elastic modulus and Poisson's ratio were carried out based on the requirements given by ASTM. Abraham cone was used to analyze the quality of freshly placed concrete and assess its workability using slump test. The test setup is shown in Figure 1.



Figure 1. Setting up (Source: documentation)

RESULTS AND DISCUSSIONS

1. Marble dust content

Physically, marble dust is bright white and has a specific gravity of 2.79. Marble dust has a fine grain size with 100% of the granules passing through the No.200 sieve with a diameter of 0.075 mm. The very fine grains of marble dust it to fill the gaps between the aggregates so that the concrete becomes compact and produces high strength. Because marble dust is used in place of some of the cement in pozzolan, there is a noticeable difference between conventional cement and pozzolan. In addition to its fineness, the mixed cement has higher levels of the characteristic pores and hydration(Shukla et al., 2019). The physics of marble dust can be seen in Figure 2.



Figure 2. Marble Dust (Source: documentation)

Before being used on waste concrete in the form of sludge, it is dried in an oven at $110^{\circ}\pm 5^{\circ}\text{C}$. The constant weight of marble dust was obtained after oven for 72 hours with a weight loss of 34.67%. This result shows a difference with the study conducted by (Corinaldesi et al., 2005). The weight loss of marble dust slurry over time in that study showed a weight loss of 40% within 24 hours. The high weight loss in marble dust is due to the fact that the material used in this study was originally marble dust slurry with a high-water content. The weight loss of the experimental marble dust is shown in Figure 3.

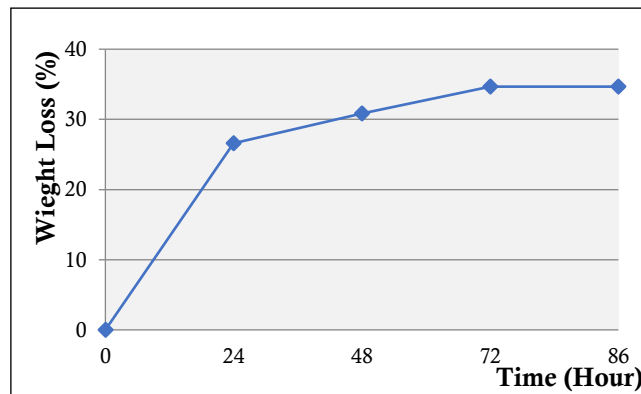


Figure 3. Weight loss of marble dust (Source: Test result)

The mineral content of marble dust was analyzed by X-Ray Fluorescence (X-RF). The analysis shows that the composition of marble dust is mostly Calcium Oxide (CaO) at 98.62%, Sulphur Trioxide (SO_3) at 0.17%, and several other elements in small amounts. The Calcium Oxide (CaO) content in marble dust does not show any reaction with the addition of water. Additionally, marble dust originating from marble is classified as a natural rock that has a large enough Oxygen (O_2) content of $\pm 49.0\%$ so that the loss of glow in marble dust is quite large (Omar et al., 2014). Based on X-RF analysis the chemical composition of marble dust, there's a significant difference when compared to the chemical composition of Portland Pozzolan Cement (PPC). Calcium Oxide (CaO) and Silicon Dioxide (SiO_2) in PPC cement are 58.66% and 23.13% respectively (BSN, 2014). The mineral content of marble dust is shown in Table 3.

Table 3. Properties of marble dust by X-RF

Minerals	Content (%)
Sulphur Trioxide (SO_3)	0,17
Calcium Oxide (CaO)	98,62
Mangan Oxide (MnO)	0,058
Cuprum Oxide (CuO)	0,038
Strontium Oxide (SrO)	0,17
Ferric Oxide (Fe_2O_3)	0,39
Iterbium Trioxide (Yb_2O_3)	0,46
Latesium Trioxide (Lu_2O_3)	0,10

(Source: Test Result)

Interpretation of the spectra with X-RF shows that the highest element as a peak is Calcium (Ca), indicating that the concentration of this element dominates. Some other elements found in marble dust include S, Cu, Fe, Mn, Lu, Sr, dan Yb in few amounts. Test result interpretation of X-RF Spectra is shown in Figure 4.

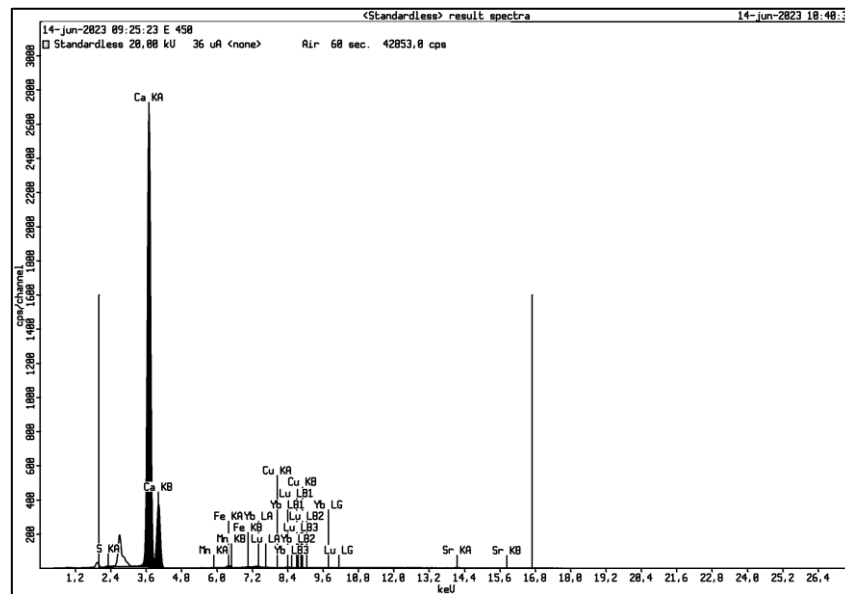


Figure 4. Interpretation of XRF Spectra (Source: Test result)

2. Slump Test

The slump value reveals whether fresh concrete is workable. Without marble dust, conventional concrete has a slump of 120 mm. Concrete that contains marble dust is more workable than concrete that doesn't. The inclusion of 10% marble dust by weight of cement produced a slump test value of 145 mm, whereas the usage of 5% marble dust produced a slump value of 150 mm. However, the use of marble dust shows a good effect on the workability of fresh concrete. The slump test result is shown in Figure 5.

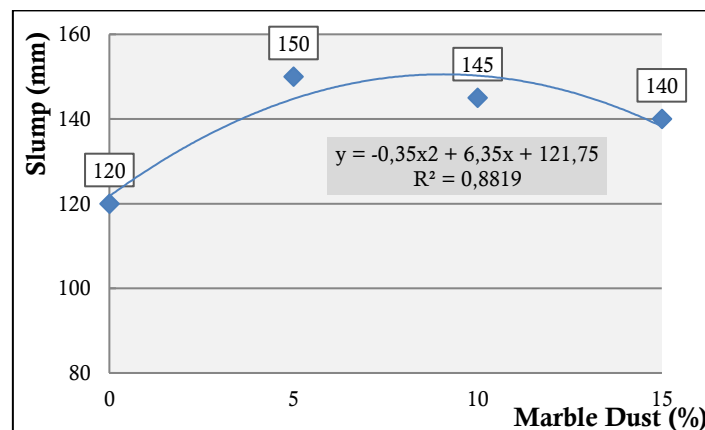


Figure 5. Slump test results (Source: Test result)

3. Compressive Strength

Compressive strength testing is carried out by progressively applying loads to concrete cylinder specimens, the compressive strength of the material can be calculated. Concrete made normally and without marble dust has a compressive strength of 22.36 MPa. The compressive strength of the concrete increased with the addition of 5% marble dust, reaching 25.31 MPa. With the reduction in cement content, the compressive strength decreased by 2.7% from concrete without the use of marble dust of 21,76 MPa. Due to considerations of optimizing waste utilization and reducing carbon emissions, the use of 6.62% marble dust is considered the most optimal with concrete compressive strength experiencing an increase of 11.77% from concrete without using marble dust. The compressive strength results for different variations of marble dust are shown in Figure 6.

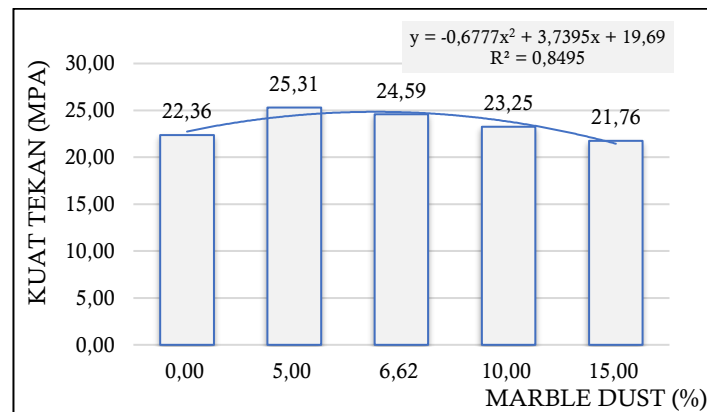


Figure 6. Compressive strength (Source: Test result)

4. Modulus of Elasticity

The modulus of elasticity of normal concrete without the use of marble dust is 21.331 MPa. The modulus of elasticity increases with the use of marble dust on concrete, the highest modulus of elasticity is shown by concrete with variations of 5% marble dust of 25821 MPa. The use of marble dust of 10% shows a concrete modulus of elasticity of 24.036. The increase in elastic modulus indicates that the density of concrete increases with the use of marble dust. However, excessive use of marble dust can cause a decrease in the modulus of elasticity. It can be seen that at 15% marble dust percentage the elastic modulus value is 22,266 MPa. The complete results of the concrete modulus of elasticity test can be seen in Figure 7.

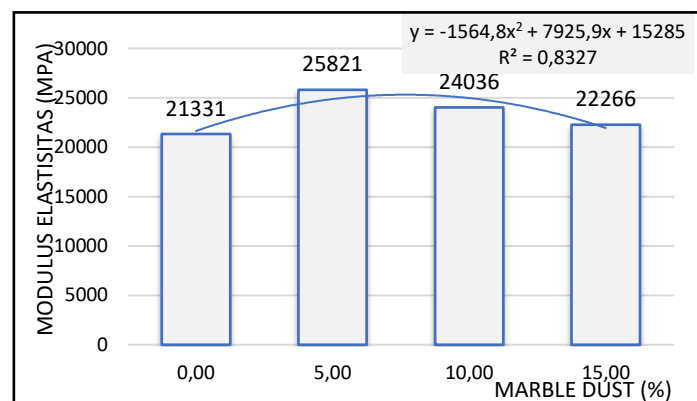


Figure 7. The modulus of elasticity (Source: Test result)

The use of marble dust showed a significant effect on the stress-strain curve of the concrete. The maximum strain in this study could not be achieved due to inaccurate measurement of the strain after the concrete cracked. The test results show that the stress-strain curve of concrete without marble dust is more sloping. The sloping line indicates that the lower the compressive strength of the concrete, the greater the strain. The use of marble dust causes relatively smaller strains at the same load level, characterized by a sharper stress-strain curve. Test results of the concrete modulus of stress-strain curve of concrete can be seen in Figure 8.

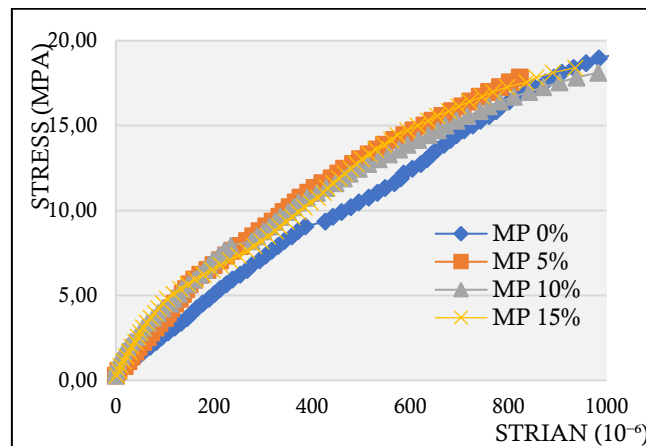


Figure 8 Test Result Stress - Strain (Source: Test result)

5. Poisson's ratio (μ)

A small Poisson's number indicates that the transverse strain is relatively small. The materials used, the density of the concrete and the cohesiveness of the mix have an effect in determining the Poisson number. If concrete with good density gives a small Poisson number, this indicates that the concrete is of good quality. Without the usage of marble dust, the Poisson's ratio for regular concrete is 0.20. A Poisson's ratio of 0.18 results from a fluctuation of 5% marble dust. More marble dust is added, and the Poisson's ratio decreases. The results of the concrete Poisson's ratio (μ) test are shown in Figure 9.

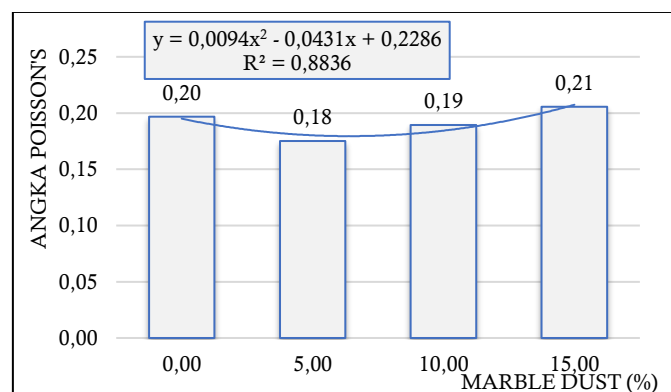


Figure 9. Poisson's ratio (Source: Test result)

CONCLUSION AND SUGGESTIONS

Conclusion

Based on X-Ray Fluorescence (X-RF) analysis the chemical composition of marble dust, there's a significant difference when compared to the chemical composition of portland pozzolan cement (PPC). Calcium Oxide (CaO) and Silicon Dioxide (SiO₂) in PPC cement are 58.66% and 23.13%, where as in marble dust the CaO content is 98.62% Calcium Oxide (CaO) at 98,62%, Sulphur Trioxide (SO₃) at 0.17%, and several other elements. Unfortunately, the Calcium Oxide (CaO) content in marble dust does not show any reaction with the addition of water. Marble dust may be used as a filler in concrete, which uses less cement, according to physical and chemical analysis. Marble dust is used in concrete because its tiny grains may fill the crevices between the aggregates, improve the concrete's cohesiveness, and raise the density of the mixture. In addition to lessening the environmental effect of trash, using marble dust in concrete also results in concrete that has higher mechanical qualities.

High compressive strength, a high elastic modulus, and a low Poisson's ratio define concrete's advantageous mechanical qualities. The test findings revealed that the marble dust content in the mixture at 6.62% produced the best results. Using 10% marble dust boosted the mechanical qualities of concrete, but the rise was not much greater. When 15% marble dust is used, the compressive strength is only slightly reduced. The advantage of using marble dust as a filler in concrete is that it increases the concrete's compressive strength by 11.77% when used at a proportion of 6.62%.

Suggestion

The reduction of cement in concrete not only provides an advantage to solve the waste problem that occurs in the marble industry area but also reduces the impact of carbon emissions. Furthermore, the utilization of marble industry waste as concrete aggregate needs to be studied to optimize waste utilization and reduce the impact of the industry on the environment and it is also necessary to develop a machine-based waste handling system.

REFERENCES

- Aliabdo, A., Elmoaty, A. E. M. A., & M. Auda, E. (2014). Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials*, 50, 28–41.
- ASTM. (2021). *ASTM Book of Standards Volume 04.02 Concrete and Aggregates*.
- BPS Kabupaten Tulungagung. (2022). *Kabupaten Tulungagung dalam Angka 2022* (1st ed., Vol. 1). CV. Azka Putra Pratama.
- BSN. (2012). *Standar Nasional Indonesia Tata cara pembuatan rencana campuran beton normal*.
- BSN. (2014). *Semen Portland Pozzolan*.
- Corinaldesi, V., Moriconi, G., Naik, T. R., & Toronto, C. (2005). Center for By-Products Utilization CHARACTERIZATION OF MARBLE DUST FOR ITS USE IN MORTAR AND CONCRETE Characterization of Marble Dust for its Use in Mortar and Concrete. In *Chair of the ASCE Technical Committee on Emerging Materials*.
- Hira, S. G., MP, N. G., Anoop, S. G., Gaurav, N., & Singh, A. (2016). A Review Article on Manufacturing Process of Cement, Environmental Attributes, Topography and Climatological Data Station: IMD, Sidhi M.P. In ~ 47 ~ *Journal of Medicinal Plants Studies* (Vol. 4, Issue 4). <https://www.researchgate.net/publication/328698368>
- Kajaste, R., & Hurme, M. (2016). Cement industry greenhouse gas emissions - Management options and abatement cost. *Journal of Cleaner Production*, 112, 4041–4052. <https://doi.org/10.1016/j.jclepro.2015.07.055>
- Omar, O. M., Abd Elhameed, G. D., Sherif, M. A., & Mohamadien, H. A. (2014). Influence of limestone waste as partial replacement material for sand and marble dust in concrete properties. *HBRC Journal*, 8(3), 193–203. <https://doi.org/10.1016/j.hbrcj.2012.10.005>
- Oza, R. B., Kangda, M. Z., Agrawal, M. R., Vakharia, P. R., & Solanki, D. S. M. (2022). Marble dust as a binding material in concrete: A review. *Materials Today: Proceedings*, 60, 421–430. <https://doi.org/10.1016/j.matpr.2022.01.278>
- Shelke, V. M., Pawde, Y., & Shrivastava, R. R. (2014). “Effect of marble dust with and without silica fume on mechanical properties of concrete.” In *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)* (Vol. 1, Issue 1). www.iosrjournals.org
- Shukla, A., Gupta, N., & Gupta, A. (2019). Development of green concrete using waste marble dust. *Materials Today: Proceedings*, 26, 2590–2594. <https://doi.org/10.1016/j.matpr.2020.02.548>
- Thakur, A. K., Pappu, A., & Thakur, V. K. (2018). Resource efficiency impact on marble waste recycling towards sustainable green construction materials. *Current Opinion in Green and Sustainable Chemistry, Published by Elsevier*, 13, 91–101.
- Tressmann, D. M. G. A., Pedroti, L. G., & Carvalho, A. F. de. (2020). Research into the use of marble waste as mineral filler in soil pigment-based paints and as an active pigment in waterborne paints. *Construction and Building Materials*, 241(4).