Sürdürülebilir Mühendislik Uygulamaları veTeknolojik Gelişmeler Dergisi
Journal of Sustainable Engineering Applications and Technological Developments
2023, 6(2): 167-179

Mühendislik Kırşehir Yöresi Atık Mermer Tozunun Tuğlanın Özelliklerine Etkisi

The Effect of Waste Marble Powder on the Engineering Properties of the Brick in Kırşehir Region

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ÖZET

Bu çalışmada, Kırşehir yöresi atık mermer tozunun çevre dostu tuğla üretiminde kullanılabilirliğinin araştırılması hedeflenmiştir. Bu hedef doğrultusunda atık mermer tozu kullanılarak fiziksel ve mekanik açıdan normal tuğlaya göre daha üstün özelliklere sahip çevre dostu tuğla üretimi amaçlanmıştır. Çalışma kapsamında, killi toprak içerisine, Kırşehir yöresinden çıkarılan atık mermer tozu %10, %20, %30, %40 ve %50 oranlarında ikame edilerek katkılı tuğla üretilmiştir. Üretilen numunelere, suya doygun birim hacim ağırlık, porozite, su emme (ağırlıkça), donma çözülme etkisi, sülfat etkisi, basınç dayanımı ve eğilmede çekme dayanımı deneyleri yapılmıştır. Sonuç olarak, atık mermer tozu miktarının artmasıyla, suya doygun birim hacim ağırlığında azalma görülürken, porozite, su emme (ağırlıkça), donma çözülme etkisi, sülfat etkisi değerlerinde artış meydana gelmiştir. Mekanik deneylerde ise basınç dayanımı azalırken, eğilmede çekme dayanım değerinde artış olduğu tespit edilmiştir. Ayrıca uygun miktarlarda (%10) atık mermer tozu ikamesinin tuğla özelliklerini iyileştirebileceği sonucuna varılmıştır.

Anahtar Kelimeler: Atık mermer tozu, tuğla, fiziksel özellik, mekanik özellik, Kırşehir.

ABSTRACT

In this study, it is aimed to investigate the usability of waste marble dust from Kırşehir region in the production of environmentally friendly bricks. In line with this goal, it is aimed to produce environmentally friendly bricks with superior physical and mechanical properties compared to normal bricks by using waste marble dust. Within the scope of the study, blended brick was produced by substituting waste marble dust extracted from Kırşehir region at the rates of 10%, 20%, 30%, 40% and 50%. The water-saturated unit weight, porosity, water absorption (by weight), freeze-thaw effect, sulfate effect, compressive strength and bending tensile strength tests were performed on the produced samples. As a result, with the augment in the amount of waste marble dust, a reduce was observed in the saturated unit volume weight, while the values of porosity, water absorption (by weight), freeze-thaw effect and sulfate effect augmentd. In the mechanical tests, it was defined that while the compressive strength reduced, the tensile strength value augmentedin bending. In addition, it was concluded that appropriate amounts (10%) of waste marble dust substitute can improve brick properties.

Keywords: Waste marble dust, brick, physical properties, mechanical properties, Kırşehir.

Doi: 10.51764/smutgd.1337550

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1. INTRODUCTION

Nowadays, raw material shortage and high energy consumption have become a big problem for most industries due to the rapid augment in raw material consumption (Göl vd., 2023). The brick sector, which is one of these sectors, has a lot of problems in terms of raw materials and high energy consumption. Brick is an indispensable building material in the construction industry due to its low cost, high strength and easy use (Khitab and Anwar, 2016).

In the production of bricks, one of the oldest building materials, useful clay soil, which is important for growing valuable crops, is used (Demir, 2009; Okunade, 2008; Gorai, 2018). The use of clay bricks in adobe house construction dates back to 8000 BC (Bui et al., 2009; Calatan et al., 2020).

The main material of brick is clay (Nabikoğlu, 2017). Approximately 340 billion tons of clay is used annually for brick production (Pawar and Garud, 2014). As a result of the reduce of clay by using in brick production, erosion, reduce of water table etc. problems will be inevitable (Ramakrishnan et al., 2023).

The increasing use of clay as a raw material in production has resulted in an alarmingly high variance in this natural material (Zhan, 2014, Pawar and Garud, 2014). Therefore, it has led many researchers to find alternative sources or ways to recycle the waste generated by various industrial processes (Ramakrishnan et al., 2023; Göl et al., 2022).

As building and construction technologies require many natural resources, sustainable construction has been developed to preserve these resources, focusing on the reuse of industrial waste and by-products (Tahwia et al., 2021; Abdellatief et al., 2023).

As a result, marble powder (Ricardo et al., 2015), sludge from water treatment plants (Haniegal et al., 2020), fly ash (Murugesan et al., 2017), sugarcane bagasse (James and Pandian, 2017), rice husk ash (RHA) (Sutas, 2012; Manni et al, 2019; Andreola et al., 2021), waste glass powder (Peng et al., 2023; Zhang et al., 2023), sawdust (Olaiya et al., 2023), quarry powder (Padmalason et al., 2023; Nisa and Singh, 2023) and eggshell powder (Ngayakamo et al., 2020) are some waste materials used in brick production.

Within the scope of the study, waste marble powder was used as industrial waste. Marble powder wastes are stored in nature as sludge, which leads to environmental pollution and causes serious damage to the vegetation in the vicinity (Öztürk, 2018; Filiz et al., 2010).

All these were taken into consideration and the study aimed to investigate the usability of marble powder from Kırşehir region in the production of environmentally friendly bricks. As a result of the study, it was targeted to produce environmentally friendly bricks with superior physical and mechanical properties compared to standard bricks.

2. MATERIAL AND METHOD

2.1. Material

2.1.1. Marble Powder

The samples of waste marble powder doped bricks produced within the study were taken from Kırşehir Granit Mermer A.Ş. located in Kırşehir city center. The grain density of the waste marble powder is 2.69 g/cm3. The chemical properties of the marble powder are presented in Table 1. The image of the waste marble powder with white color and 2 μ grain size is given in Figure 1.

Table 1. Chemical properties of waste marble powder

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
MT (%)	38,30	15,32	8,23	33,61	0,58

Figure 1. Waste marble powder

2.1.2. Clay Soil

The waste marble powder added brick samples produced in the study were obtained from the central district of Kayseri province, which was used as raw material. The mineralogy of the clay soil examined at Erciyes University Central Research Laboratory is given in Table 2. It is seen that the highest proportion of the elements whose weight ratios are given in the table belongs to silicon. Silicon is followed by Oxygen Calcium and Aluminum.

Table 2. Mineralogical values of clay soil

Element	Si	O	Ca	Al	Fe	Nb	K	Mg
Weight (%)	38,63	22,78	14,92	9,48	6, 01	6,21	2,58	2,97

2.1.3. Mixing Water

The mains water of Kayseri province, which does not contain organic matter and is potable, was preferred as the mixing water in the production of samples with waste marble powder doped.

2.2. Method

2.2.1. Production of samples

Clay soil, waste marble powder and mixing water were provided for the production of waste marble powder doped brick samples to be produced in the study and brought to the laboratory where the production will be carried out. Before being brought to the laboratory, the quartering method was used to extract the clay soil. Then, the clay soil was ground to a grain diameter of 2 µ with the help of a roller crusher. The waste marble powder obtained from the company was sieved through a 1 millimeter sieve and the undersize material was removed. The recipe given in Table 3 was prepared for the production of brick samples. REF given in the recipe means reference sample, WMP10 means brick sample with 10% waste marble powder doped, WMP20 means brick sample with 20% waste marble powder doped, WMP30 means brick sample with 30% waste marble powder doped, WMP40 means brick sample with 40% waste marble powder doped.

Table 3. Mixing Recipe

	Marble Waste (%)	Clay Soil (%)
REF	--	100
WMP10	10	90
WMP20	20	80
WMP30	30	70
WMP40	40	60

In the test study, the dry materials, clay soil and waste marble powder, were firstly mixed dry for 1 minute. Then the mixing water was gradually added to the dry mixture and mixed at low setting for 1.5 minutes and 1.5 minutes at high setting to obtain brick dough. The dough was placed in greased steel molds with dimensions of 4x4x16 cm.

Afterwards, 60 hits were applied to the moulds and compression was performed. After the compression process was completed, the samples were left in the mould for 24 hours. The semi-finished brick samples were then subract from the mould and dried in a semi-open area for 48 hours. After drying, they were placed in the firing furnace and the furnace temperature was gradually augmentd. The brick specimens were fired at 900 ^{o}C. The fired samples were cooled without removing them from the furnace. After the cooling process was completed, they were removed from the furnace (Figure 2) and physical and mechanical tests were performed.

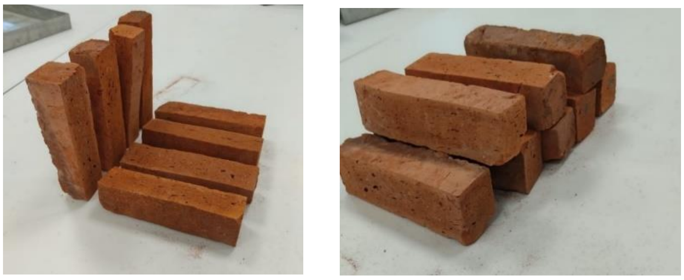

Figure 2. Waste marble powder doped brick sample

2.2.2. Physical experiments

- **Water Saturated Unit Volume Weight**

The water saturated unit volume weights of the waste marble powder doped brick samples were based on the TS EN 772-4 standard. According to the standard, the brick samples were boiled in a container filled with water for about 3 hours. The suspended weights (P1) of the samples taken out of the water were defined. The water was then removed from the surface with a cloth and the water-saturated dry weights (P2) were determined. Finally, the samples were dried in an furnace at ±105 oC for 1 day (P3) (Figure 3). All the values obtained were substituted into the equation below to obtain the water saturated unit volume weight.

Water Saturated Unit Volume Weight (g/cm³) = P3/P2-P1

Figure 3. Drying the samples in an furnace

- **Water Absorption (By Weight)**

Another physical test applied to the samples was water absorption test. Within the scope of this test, the samples were left in the curing pool for 24 hours. At the end of one day, the outer surface of the samples taken out of the curing pool was wiped with a cloth and measured with a delicate balance (Psh). The samples were then dried in an furnace until they reached constant weight and then measured with a precision balance (P0). The values obtained were substituted in the formula below and the water absorption (by weight) value was found.

Water Absorption (By Weight) As = (Psh-P0)/P0

- **Porosity**

It values of the waste marble powder doped brick samples were based on TS EN 772-4 standard. According to the standard; the brick samples were boiled in a container filled with water for about 3 hours. The suspended weights (P1) of the samples taken out of the water were weighed. Then, the water was removed from the surface with the help of a cloth and the water saturated dry weights (P2) were defined. Finally, the samples were dried in an furnace at ±105 oC for 1 day (P3). Porosity values were found by substituting all the values obtained in the equation given below.

Porosity (%) = ((P2-P1) / (P2-P3)) x 100

- **Freeze-Thaw Effect**

The freeze-thaw test of the samples produced within the scope of the study was carried out with the test device given in Figure 4.5. In the first step of the experiment, the samples were held in 20 oC water for 12 hours to become water saturated samples. In the second step, the samples taken out of the water were then placed in the device whose cooling rate could drop to -20 oC within 4 hours and kept at this temperature for 12 hours. In the third step, the samples were taken from the freezer and placed in water at 20 ^{o}C and kept for 12 hours. Special care was taken to ensure that no ice remained on the samples. These three steps represent a single cycle. This cycle can be repeated as many times as desired. Within the scope of the study, this cycle was repeated 25 times. At the end of the experiment, the samples were subjected to compressive strength test.

- **Sulfate Effect**

The sulfate effect test of waste marble powder doped brick samples was carried out based on ASTM C1012. According to the standard, the produced brick samples were left in a water-filled container with a 5% sulphate solution for 30 days. Finally, the samples were subjected to compressive strength test.

2.2.3. Mechanical experiments

- **Compressive Strength**

One of the experiments performed to define the mechanical properties of the samples is the compressive strength test. In the test, a constant amount of force is applied to the brick sample of certain dimensions by means of a pressure press device without impact. The force continues to be applied until the sample starts to break. The application is stopped at the moment of fracture. The compressive strength value is found by dividing the force value that causes the fracture of the brick sample, whose cross-sectional area was previously calculated, by the cross-sectional area. Figure 4 shows the compressive strength test device of the samples.

Figure 4. Compressive Strength

- **Flexural Strength**

Another test for the detection of mechanical properties is the flexural strength test. In the test, the simple beam method loaded from the centre point is applied to the sample. In this method, a singular load is applied to the sample at its centre point. Figure 5 shows the flexural strength test device of the samples.

Figure 5. Flexural Strength

3. RESEARCH RESULTS AND EVALUATION

3.1. Water Saturated Unit Volume Weight

This test values applied to the samples produced within the scope of the study are given in Figure 6. When the figure is analysed, it is detected that the addition of waste marble powder has a positive effect on the water saturated unit volume weight value of the brick. The water saturated unit volume weight values reduced with the augment in the amount of waste marble powder. The highest value was obtained from the reference sample with 2.08 g/cm^3 and the minimum value was obtained from the samples with 50% waste marble powder additive with 1.56 g/cm^3.

It was defined that brick samples reduced at rates ranging from 4% to 25% with the substitution of waste marble powder. These rates were calculated to be 4%, 10%, 18%, 22% and 25%, respectively. This is thought to be due to the fact that the unit volume weight of waste marble powder is lower than the unit volume weight of clay. The reduce in the water saturated unit weight in brick samples is accepted as an indicator of the augment in the porosity of waste marble powder (Sütçü and Akkurt 2009).

When the studies in the literature are analysed; Eliche-Quesada et al. found that the water saturated unit volume weight of fired clay bricks containing 20% waste marble powder reduced up to 9%, Münir et al. found that 25% waste marble powder reduced the water saturated unit volume weight of brick samples by 15%. In addition, Dhanapandian et al., Aydın and Karakurt obtained similar results to the study in their study.

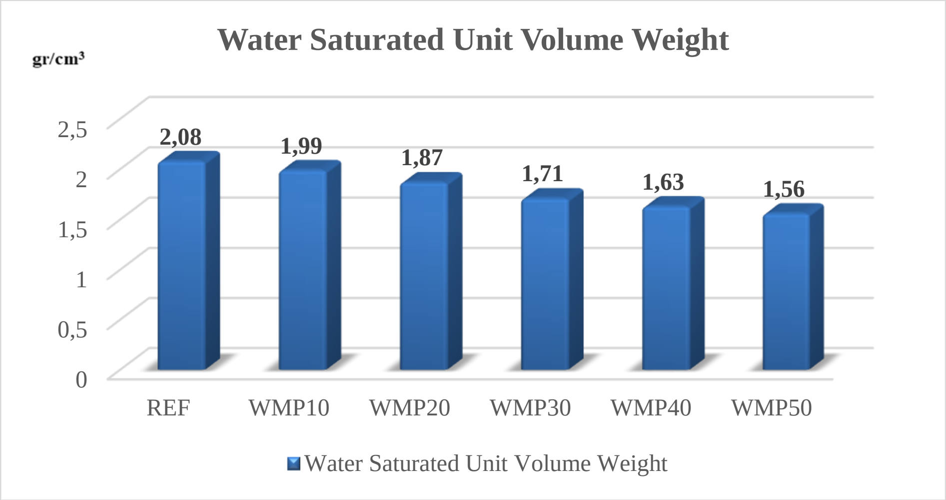

Figure 6. Graph of water saturated unit volume weight

3.2. Porosity

Porosity, which means the void in the sample structure, is a very important parameter for the engineering properties of the samples. Porosity values of the samples produced within the scope of the study are given in Figure 7. When the figure is analysed, it is seen that the porosity values vary between 22.1% and 51.3%. The minimum porosity value was obtained from the reference sample and the highest porosity value was obtained from the WMP50 sample. In other words, the porosity value augmentedwith the augment in the amount of waste marble powder. The values found are 22.1%, 25.3%, 30.5%, 38.7%, 45.4%, 51.3% respectively.

When the samples with waste marble powder doped samples are compared with the reference sample; the porosity value of WMP10 sample augmentedby 14% compared to the reference sample. This augment is 38% in WMP20, 75% in WMP30, 105% in WMP40 and 132% in WMP50.

The reason why waste marble powder augments porosity is that waste marble powder is composed of CaCO3, which produces CO2 gas and causes porosity to augment. The CaO released is a reactive compound (Sütçü and Akkurt, 2009). This can change the quartz phase of the bricks into new phases such as calcium alumino-silicates and change the brick properties (Sütçü et al. 2015). The study by Bilgin et al. also supports our study (Bilgin et al., 2012).

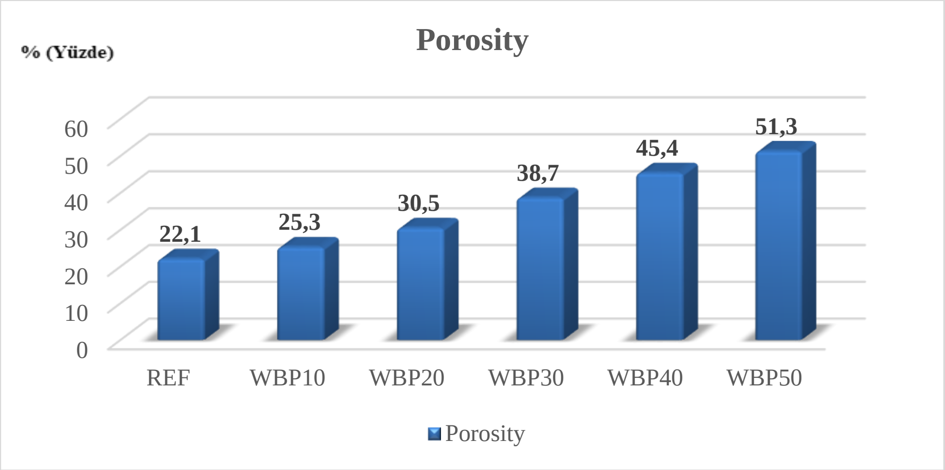

Figure 7. Graph of Porosity

3.3. Water Absorption (By Weight)

Figure 8 shows the it’s values of the reference and waste marble powder doped brick samples. When the graph in the figure is analysed; it is detected that the water absorption rates vary between 20,8% and 38,6%. The minimum value was obtained from the reference sample and the maximum value was obtained from the samples with 50% waste marble powder additive. In other words, the water absorption rate augmentedwith the augment in the proportion of waste marble powder.

When the waste marble powder doped samples were compared with the reference sample; the water absorption rate of WMP10 sample augmentedby 15.8% compared to the reference sample. This augment is 31.7% in WMP20, 44.7% in WMP30, 69.6% in WMP40 and 85.5% in WMP50.

The results obtained and previous studies show that there is a linear relationship between porosity and water absorption values (Sütçü and Akkurt 2009; Bilgin et al. 2012). The maximum water absorption limit reported by various researchers shows that it varies between 20% and 40% and supports our study (Saboya et al. 2007; Kazmi et al. 2016). In addition, in some studies, it was observed that the amount of water absorption augmentedwith the augment in the amount of waste marble powder as in the study (Bilgin et al., 2012; Cobo-Ceacero et al., 2018).

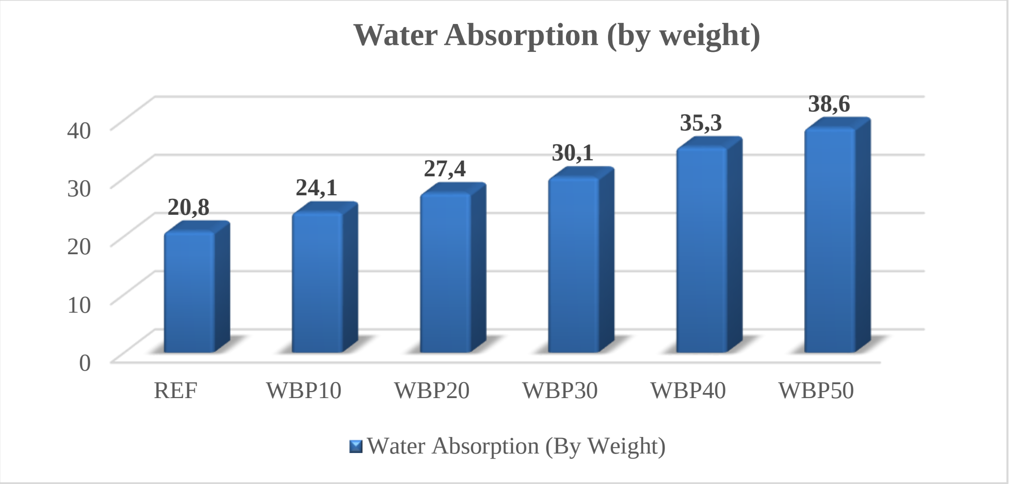

Figure 8. Graph of water absorption

3.4. Freeze-Thaw Effect

It's values of the samples are presented in Figure 9. When the figure is analysed, it is seen that the freeze thaw values vary between 14.3% and 34.1%. Again, the minimum value was obtained from the reference sample and the maximum value was obtained from the WMP50 sample. The values found are 14,6%, 17,6%, 20,5%, 25,9%, 29,6%, 34,1% respectively. As can be seen from the values, the freeze thaw value augmentedwith the augment in the amount of waste marble powder.

When the waste marble powder doped samples are compared with the reference sample; the freeze-thaw effect of WMP10 sample augmentedby 23% compared to the reference sample. This augment is 43.3% for WMP20, 81.1% for WMP30, 106.9% for WMP40 and 138.4% for WMP50.

The ASTM C67 standard considers bricks to be freeze-thaw resistant if they do not crack during the freeze-thaw cycle or if the mass loss does not exceed 3%. As a result of the test performed within the scope of the study, all samples were subjected to mass loss over 3% and cracking was observed. Porosity of bricks is an important factor for freeze-thaw resistance (Davison 1980). In a previous study, it was reported that brick samples with high pore volumes were subjected to higher mass loss, which reduced durability (Netinger et al., 2014). This study supports our study.

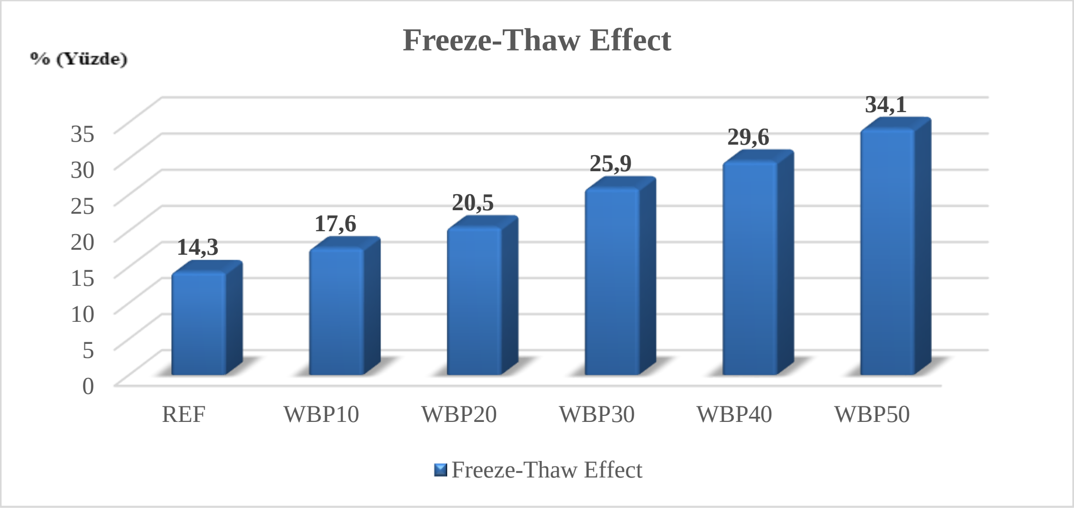

Figure 9. Graph of freeze-thaw strength

3.5. Sulfate Effect

Figure 10 shows the mass gain and compressive strength reduction rates of doped and un-doped brick samples exposed to sulphate effect.

When the compressive strength was analysed, a reduce in compressive strength occurred with the augment in the amount of waste marble powder. The reduce in compressive strength of the samples varied between 12.8% and 44.5 MPa. The lowest compressive strength loss was obtained from the reference sample. It is thought that the reason for the reduce in compressive strength is that the salt crystals in the pores of the bricks create pressure and cause internal microcracks, resulting in a reduce in compressive strength. The reference sample has the lowest compressive strength loss since it has less porous structure compared to the samples with waste marble powder additives.

Since the pores of the brick samples were filled with salt crystals, it caused mass gain. Since the porosity of the samples doped with waste marble powder was higher, the mass gain augmentd. The lowest mass gain was obtained from the reference sample with the minimum porosity value and the highest mass gain was obtained from the WMP50 sample with the maximum porosity value. The mass gain values are 11.3%, 16.9%, 25.2%, 30.7%, 35.1% and 41.4%, respectively.

When the literature was analysed, the studies conducted by Naik et al. and Münir et al. presented similar results with the study.

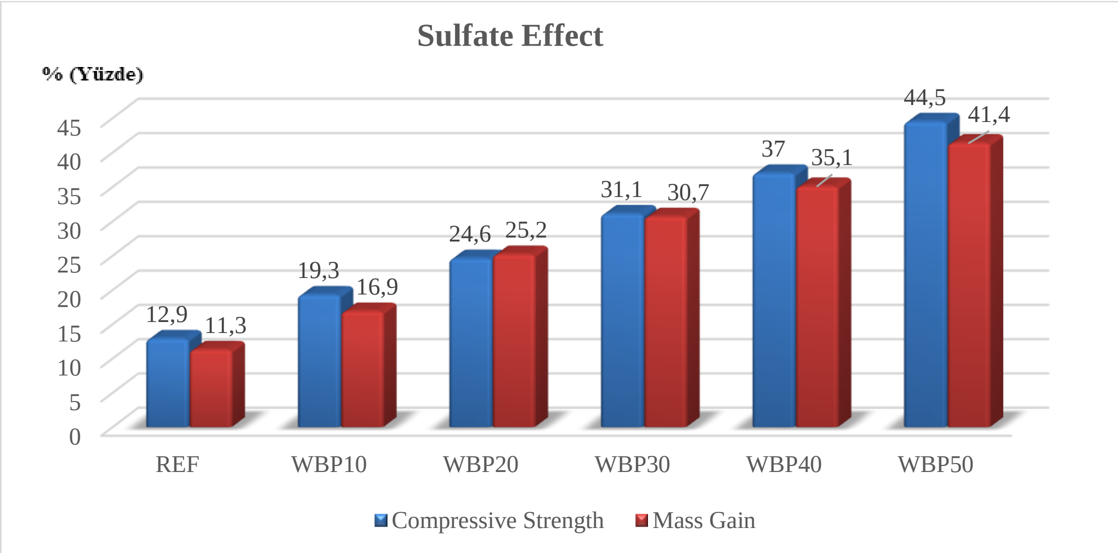

Figure 10. Graph of sulphate effect

3.6. Compressive Strength

One of the tests performed to determine the mechanical properties is the compressive strength test. Figure 11 presented the graph of compressive strength values of waste marble powder doped brick samples. In the graph, it is seen that the compressive strength values of the waste marble powder doped brick samples are lower than the reference sample. In addition, it was determined that the compressive strength reduced with the augment in the waste marble powder substitution rate. While the reference sample had the highest compressive strength with 4.4 MPa, the lowest compressive strength was obtained from WMP50 sample with 1.98 MPa. The compressive strength of the samples are 4.4, 4.01, 3.54, 3.01, 2.5, 1.98 MPa respectively.

When the waste marble powder doped samples are compared with the reference sample; the compressive strength of WMP10 sample reduced by 8.8% compared to the reference sample. This reduce is 19.5% in WMP20, 31.5% in WMP30, 43.1% in WMP40 and 55% in WMP50.

According to TS 704, bricks with a compressive strength between 4-5 MPa are classified as medium strength bricks and bricks with a compressive strength between 2.5-3.9 MPa are classified as low strength bricks. In this study, the reference and WMP10 samples are classified as medium strength bricks, while WMP20, WMP30, WMP40 and WMP50 samples are classified as low strength bricks.

Density, porosity and pore size of brick samples are the main parameters affecting the compressive strength (Aouba et al. 2016). It is seen that there is an inversely proportional linear relationship between the compressive strength of bricks and porosity values. In addition, when waste marble powder is fired at high temperatures, the carbonates in it burn and cause the porosity value to augment. This has a negative effect on compressive strength

(Kazmi et al., 2016-a; Kazmi et al., 2016; Sütçü et al., 2015).

The brick samples with 10% waste marble powder substitution achieved compressive strength that met certain limit. Therefore, it can be used effectively in sustainable, cost-effective wall construction. Some studies in the literature are consistent with the values obtained in our (Bilgin et al., 2012; Cobo-Ceacero et al., 2018; Ionescu et al., 2023).

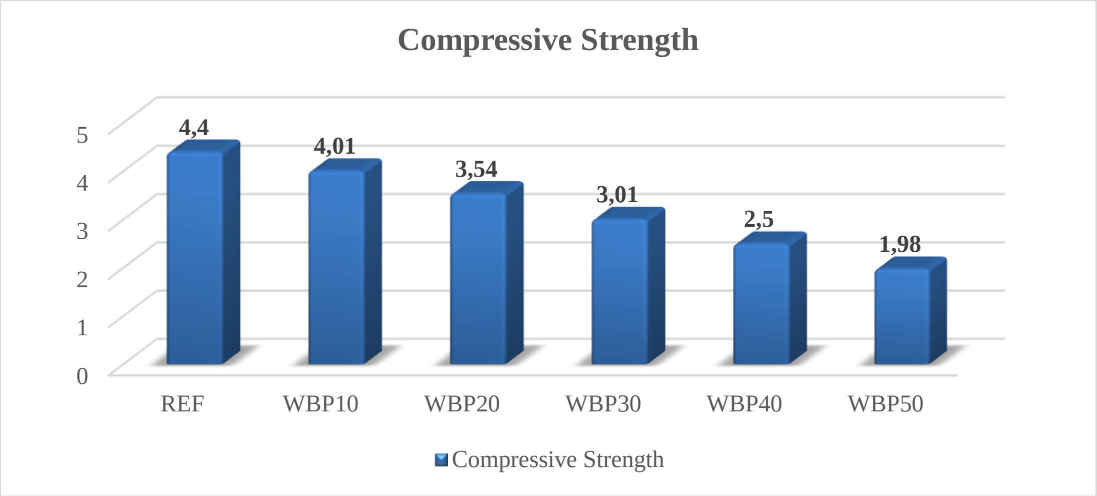

Figure 11. Compressive strength values of the samples

3.7. Flexural Strength

Another test performed to determine the mechanical properties is the flexural strength test. Figure 12 shows the flexural strength values. When the figure is analyzed, it is seen that the substitution of waste marble powder augments the flexural strength values of the samples. The minimum value was obtained from the reference sample and the maximum value was obtained from the WMP50 sample. Flexural strength values vary between 0.64-1.15 MPa. According to ASTM C67 standard, the minimum flexural strength value of bricks to be used in wall construction should be 0.65 MPa. In this case, the flexural strength values of all brick samples doped with waste marble powder meet the standard. In addition, the flexural strength values of the brick samples are related to their microstructure, which becomes more porous with increasing waste marble powder substitution (Bilgin et al., 2012; Cobo-Ceacero et al., 2018).

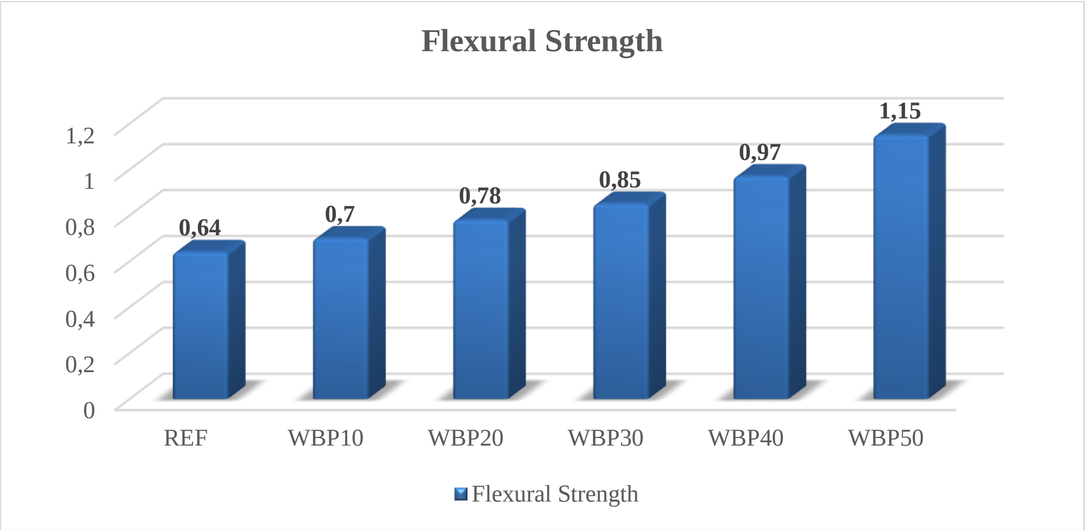

Figure 12. Flexural strength values of the samples

4. CONCLUSION AND RECOMMENDATIONS

Within the scope of the study, waste marble powder from Kırşehir region was substituted into the clay at different ratios (10%, 20%, 30%, 40%, 50%) and additive bricks were produced. Physical and mechanical tests were performed on these brick samples. The data obtained as a result of the study were evaluated and the following conclusions were drawn.

- ✓ The water saturated unit volume weight values reduced with the augment in the amount of marble powder in the waste marble powder doped brick samples. The lowest value was obtained from WMP50 sample.

- ✓ As the amount of waste marble powder augmentedin the brick samples, porosity values also augmentd. The samples with the highest porosity are WMP50 samples. The augment in porosity rate caused an augment in water absorption rate.
- ✓ The water absorption values of the samples augmentedwith the augment in waste marble powder substitution, the highest water absorption rate was obtained from the WMP50 sample and the minimum water absorption rate was obtained from the reference sample.
- ✓ As a result of the freeze thaw test, it's values augmentedas the amount of waste marble powder augmentd.
- ✓ The sulfate effect augmentedwith the augment in the amount of additives in the waste marble powder doped brick samples. Under the sulfate effect, compressive strength and mass gain augmentedand the highest value was obtained from WMP50 sample.
- ✓ The compressive strength values of the brick samples reduced as the amount of waste marble powder augmentd. Samples containing 10% waste marble powder are classified as medium strength bricks and can be used in building production. The mininum compressive strength was obtained from the WMP50 sample and the maximum compressive strength was obtained from the reference sample.
- ✓ As the amount of waste marble powder augmentd, the flexural strength values of the brick samples also augmentd. All waste marble powder doped samples meet the minimum flexural strength value specified in ASTM C67 (i.e. 0.65 MPa).
- ✓ Based on these findings, it is concluded that the use of waste marble powder in brick production is a suitable option.
- ✓ The high porosity values of the brick samples doped with waste marble powder indicate that it is a porous material. Since the thermal performance of porous materials is quite good, it is recommended to apply heat transfer coefficient determination test to the samples.
- ✓ The use of waste marble powder can reduce the depletion of fertile soils.
- ✓ Bricks with 10% waste marble powder additives have values close to the reference sample and are suitable for use in sustainable brick production.
- ✓ The use of waste marble powder in clay bricks can augment the sustainability of masonry construction, reduce landfill practices and avoid potential health risks after disposal of this by-product in natural ecosystems.
- ✓ Apart from cement and concrete, waste marble powder is also recommended to be used in the production of building materials such as bricks.
- ✓ The number of academic studies on the use of waste marble powder in the construction field should be augmentd.
- ✓ The use of waste marble powder in brick production is an effective solution for waste disposal.

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