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Research Article

Mechanical properties of lightweight photocatalytic marbelite

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ABSTRACT

This study investigated the mechanical performance of lightweight photocatalytic marbelite (LPM). In the production of LPM, titanium dioxide (TiO_2) and various fiber additives were used to impart self-cleaning properties to the LPM with photocatalytic effect. In the study, fibers were added to the LPM mix at different ratios (0%, 0.5%, 1%) and unit weight, ultrasound transmission rate, bending, splitting tensile and compressive strength tests were carried out on these specimens. The mixture was prepared with perlite and polyester resin and enriched with TiO_2 and fiber additives. Perlite was used as an aggregate in the LPM and lightweighting properties were added to the specimens. The experimental results show that increasing the fiber content significantly improves the mechanical strength of the LPM. The improvement in bending strength reached 60%, while in compressive strength it reached 25% and in splitting tensile strength it reached 35%. With the addition of TiO2, the bending strength of LPM increased by 15%, while the compressive strength increased by 12% and the splitting tensile strength increased by 7%. These ratios were higher with increasing fiber content. These results suggest that LPM, which provide environmental benefits with their photocatalytic properties and improved mechanical performance, can be more effectively used in industrial applications.

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1. Introduction

Composite materials, combination of two or more materials that give superior properties compared to the individual use (Canbaz et al. 2021), are widely used in industries such as construction due to their properties such as low weight and high strength (Bhong et al. 2023). The success of these materials often depends on the properties of the components they contain and how they interact with each other. Perlite and polyester resin play an important role as the basic components of composites (Hsissou et al. 2021). Perlite is a natural volcanic glass and is known for its light weight, low density and high thermal insulation capacity (Ibrahim et al. 2020). Polyester resin enhances the properties of perlite as a durable and flexible binder. The combination of perlite and polyester resin significantly improves the thermal and mechanical properties of these composites (Arslan et al. 2023). Such composites have the potential to increase energy efficiency and improve building performance. Furthermore, evaluating the usability of these materials in various applications offers both economic and environmental benefits (Bunsell et al. 2021). Marbelite is a material that is usually produced with polyester or acrylic resins and looks like natural marble. It is a material that is more resistant to cracking and breaking, has a lower water absorption rate than natural marble, is more resistant to acidic and alkaline substances, but has a risk of deformation when exposed to extreme temperatures (Soykan 2012; Özodabaş et al. 2024).

Titanium dioxide (TiO_2) has become an important research topic in materials science due to its photocatalytic properties. TiO_2 is activated by light and can reduce surface contamination by degrading organic pollutants and microorganisms (Ünal and Canbaz 2022). The addition of TiO_2 to composite materials is an effective way of improving the environmental performance and durability of these materials (Hegyi et al. 2023). Fibers are used as a critical component to enhance the mechanical properties of composites (Azman et al. 2021). Fibers enhance

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the durability and structural integrity of composites (Bhaduri et al. 2022). The amount of fibre, which varies according to the resin ratio, can significantly affect the tensile and tear strength of composites. Fibers are known to minimize negative effects such as cracking and deformation by strengthening the microstructure of the material (Mi et al. 2020). Different fibre types and their proportions are important parameters used to optimize the performance of composites (Fu and Yao 2022), such as carbon, glass, basalt, aramid, and polypropylene (Çelik et al. 2024; Gultekin 2023). The role of fibers in composites is considered to be a critical factor for durability and structural integrity (Raju and Shanmugaraja 2021). There are many studies on the use of concrete and resins with fibers to produce different composite materials, but there are no studies on the use of marbelite with fibres. In addition, interest in studies on self-cleaning of various building material surfaces is increasing. TiO2 is added to marbelite for this purpose, but there are significant gaps in the literature on how this additive changes the mechanical properties of marbelite. This study is one of the first efforts to overcome these deficiencies. In this study, the effects of perlite, polyester resin, TiO_2 and fibers on the structure of marbelite were comprehensively investigated. The effects of perlite and polyester resin combination on mechanical properties were investigated, and the effects of TiO_2 and fibers on mechanical properties were investigated. The results show the effects of these components on the overall performance of marbelite derived materials and their usability in various applications as seen in Fig. 1.

Fig. 1. Some countertop materials used in the application (Tavşan and Küçük 2013).

2. Experimental Study

2.1. Materials

Binder: Polyester type resin was used as a binder in the study. The polyester used is TP100 type of Turkuaz Polyester (Kocaeli, Türkiye) brand. Casting-type orthophthalic based unsaturated polyester resin was used as binder. The mechanical, physical and chemical properties of the polyester resin are shown in Table 1.

Hardeners are accelerators or heat-activated chemicals that regulate the curing of polyester resin. They initiate cross-linking reactions between the resin and reactive monomers. This allows the resin to solidify. Methyl ethyl ketone peroxide (Mek Peroxide) from Turkuaz Polyester was used as hardener in the experimental study.

Table 1. Properties of polyester resin.

Viscosity Cps	Appearance	Exothermic heat, °C	Specific weight, kg/m^3	Working time, min.	Tensile str., MPa	Bending str., MPa	Hardness Barcol
350–500	Clear, liquid	175	1.17	10-15	50-60	85-95	40–42

Accelerators are used in the curing of unsaturated polyester resins with organic peroxides at room temperature. Accelerator activates the hardener and enables the reaction to start. In the experimental study, cobalt octoate from Turkuaz Polyster was used as accelerator.

- Fiber: Polypropylene fibers obtained from Şişecam Company (İstanbul, Türkiye) were used in the study. The chemical and physical properties of the fibers used in the blend are given in Table 2.
- TiO_2: The TiO_2 used in production is in the anatase phase and was sourced from Refsan (Kütahya, Türkiye). As the purity of the material is very high, no additional purification was required. The properties of the powders used in the initial stage, as reported by the manufacturers, are shown in Table 3.
- Perlite: Perlite obtained from Uzay Perlit Company (İstanbul, Türkiye) was used in the study. The chemical and physical properties of the fibers used in the blend are given in Table 4. The granulometry of the expanded perlite used in the study is shown in Fig. 2.

Table 2. Properties of fiber.

Fiber diameter, μm	Clipping length, mm	Moisture content, %	Type of binder	Amount of binder, %
13	4.5–6.0	0.07	Silane	0.7 ± 0.2

Table 3. Properties of TiO_2.

Phase	Average grain size, μm	Purity, %	Fineness, m^2/g	Density, kg/dm^3
Anatase	5	> 99	82	4.21

Table 4. Properties of perlite.

Specific weight, kg/m^3	Average grain size, mm	SiO_2, %	Al_2O_3, %	Na_2O, %	K_2O, %	MgO, %	PH
50-60	0–3	74	14	3	5	0.5	7

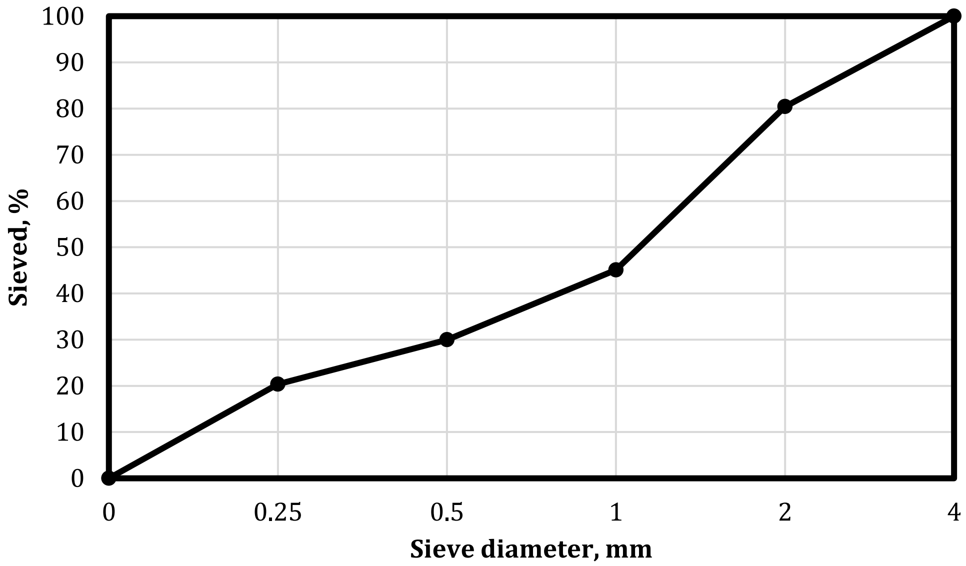

Fig. 2. Granulometry of expanded perlite used in the study.

2.2. Method and tests

The first step in specimen production was to produce control specimens. At the production stage, perlite and polyester were prepared for production in separate containers. Hardener was added to the polyester at a rate of 2% of resin and accelerator at a rate of 1%. All components were mixed until a homogeneous mixture was obtained. The mixture was poured into 4x4x16 cm metal moulds after thorough compaction to avoid voids. At the end of the setting process, the moulds were opened and the specimens were prepared for the test after 1 day.

To production of the additive specimens, polyester was mixed with perlite by adding hardener and accelerator before mixing with perlite. The mixture was then poured into the container with perlite to obtain a homogeneous mixture. TiO_2 (0% - 3% - 6% - 9%) and fibers (0% - 0.5% - 1%) were then added to the mixture in different proportions to the resin and thoroughly mixed. The resulting mixture was poured into metal moulds lubricated with moulding oil and again thoroughly compacted to avoid voids. Table 5 shows the mixing ratios of the concrete specimens.

Table 5. Mix proportion of lightweight photocatalytic marbelite.

Perlite/Polyester resin	Accelerator/Polyester resin	Hardener/Polyester resin	TiO_2/Polyester resin	Fiber/Polyester resin
0.11	0.01	0.02	0/0.03/0.06/0.09	0/0.005/0.01

Since the polymerization time can reach 7 days depending on the resin type, the tests were carried out 7 days after production. On the dried specimens, unit weights according to EN 1015-10, Ultrasonic pulse velocity according to EN 12504-4, splitting tensile tests according to ASTM D3967-16, bending tests and compression tests according to EN 196-1 were performed on 4x4x16 cm sized specimens.

3. Results and Discussion

3.1. Unit weight measurement

Fig. 3 shows the unit weight test results of the specimen with different TiO_2/resin ratios, varying with the fiber/resin ratio. From Fig. 3 it can be seen that the unit weight values of all specimens are well below the unit weight value of white marble measured as a reference. This is important for the production of low density marble. When the specimens were evaluated in isolation, an increase in the unit weight value was observed with increasing fiber content. The same situation was observed with the increase in TiO_2. In the specimens with a fiber/resin ratio of 1, the specimen with the highest unit weight value was the specimen with 9% T/R ratio with 0.9123 kg/dm^3. The reasons for this can be said to be that the unit weight of TiO_2 is higher than the unit weight of resin and resin is replaced by TiO_2. It can be said that the lowest unit weight values among the specimens were achieved by the specimen without TiO_2. If the results are evaluated in general, the use of expanded perlite, resin and TiO_2 has produced marble that is considerably lighter than white marble.

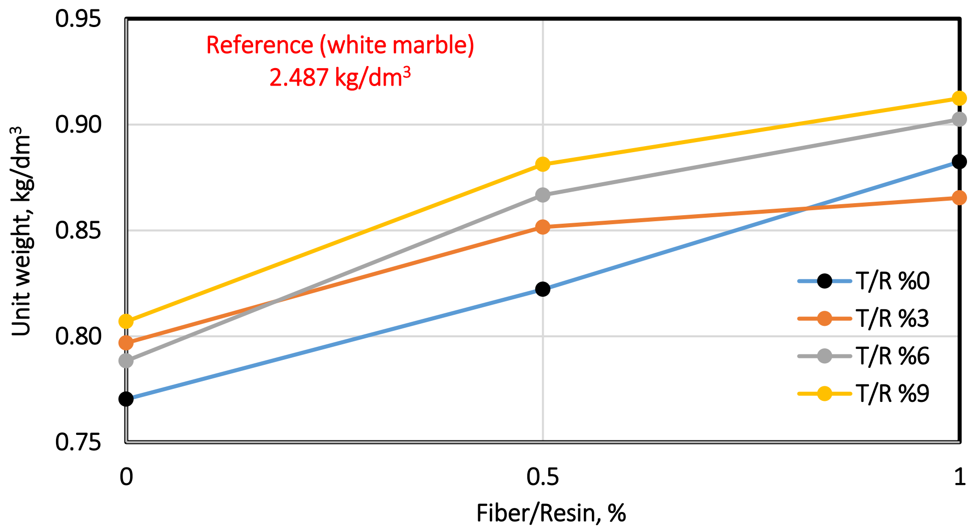

Fig. 3. Unit weight test results of the specimens.

3.2. Ultrasonic pulse velocity measurement

Fig. 4 shows the results of the ultrasonic pulse velocity test on LPM specimens. From Fig. 4 it can be seen that, in general, as the percentage of fiber in the specimen content increases, the UPV values also increase. In the fineness of the specimens with no fiber content, the specimens with the highest UPV values were those containing 6-9% TiO_2. This can be explained by the fact that TiO_2 increases the unit weight of marbelite. The UPV values increased with increasing fiber content in the specimens with the same TiO_2 and different fiber content. The UPV value of the 0% T/R specimen with 0% fiber ratio was measured to be 1.63350 km/sec. In the specimen where the fiber ratio was increased to 50%, this value was determined to be 1.74835 km/sec. The UPV value of the 0% T/R specimen with the highest fiber ratio of 100% fiber ratio was recorded as 1.7616 km/sec. The increase in UPV values with increasing fiber content is due to the fact that fibers have a conductive effect on wave propagation in concrete and increase the density of the concrete. The UPV values obtained for all constituents were higher than the reference values obtained with white marble.

In general, the experimental results achieved the desired result and confirmed the trend of increasing UPV values with increasing fiber content. These results indicate that polypropylene fiber influences the wave propagation in the internal structure of the concrete, increasing its density and homogeneity. The increase in UPV values can be used as an important parameter to evaluate the microstructural performance of the concrete and the structural effects of the fiber admixture.

3.3. Bending strength measurement

Fig. 5 shows the bending strength test results of the LPM samples. From Fig. 5 it can be seen that the bending strength increases with increasing fiber ratio. The bending strength of all specimens with 1% fiber/resin ratio reached values up to 25% higher than the bending strength value of white marble measured as a reference. This shows that the fibers in the structure of marbelite with photocatalytic properties are much superior to white marble in absorbing the shear force. Comparing the bending strength of the specimens produced, it can be seen that almost all the specimens give similar results. In this case, it can be seen that TiO_2 has no effect on the bending strength.

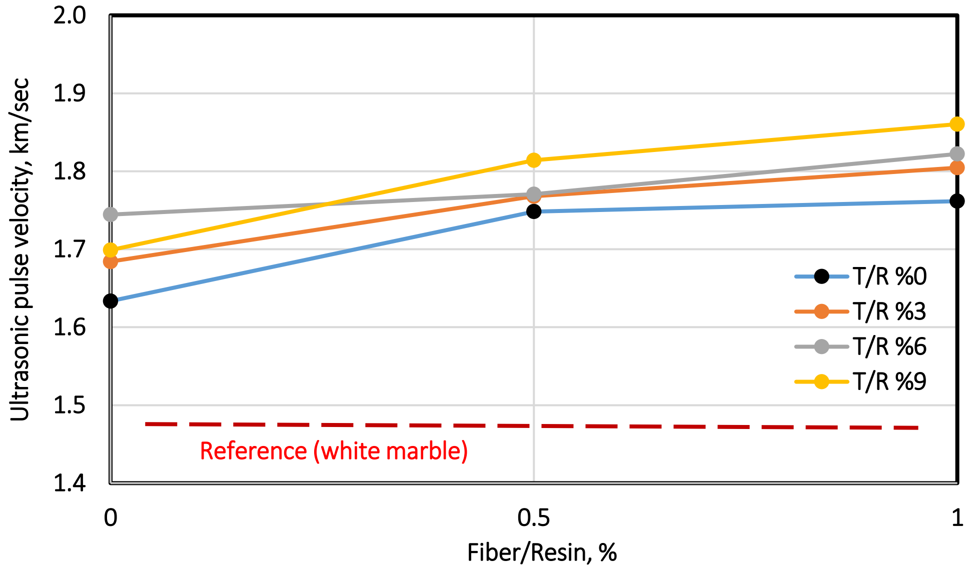

Fig. 4. Ultrasonic pulse velocity test result of the specimens.

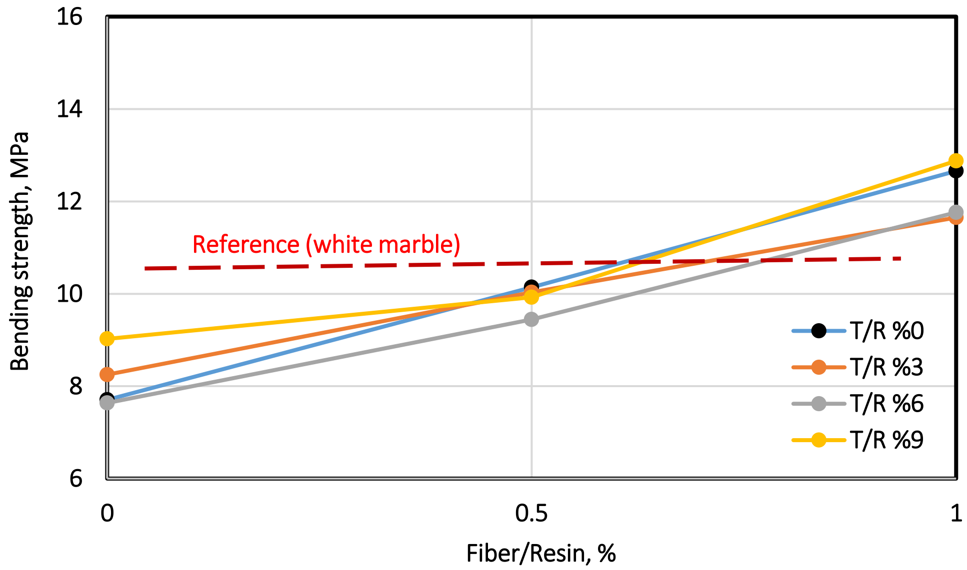

Fig. 5. Bending strength test results of the specimens.

3.4. Compressive strength measurement

Fig. 6 shows the compressive strength test results of specimens with different TiO_2/resin ratios, varying with fiber/resin ratio. From Fig. 6, high compressive strengths were generally obtained in all the specimens produced. As the fiber ratio increased, the compressive strengths also increased. The specimens with 1% Fiber/Resin ratio reached the highest compressive strength. The highest compressive strength of the specimens with 1% Fiber/Resin ratio was 31.51 MPa. It can be said that a very high strength was obtained compared to the compressive strength of white marble measured as 37.94 MPa. It is seen that the compressive strengths reached the desired level due to the microstructure formed by polypropylene fibers in LPM, the distribution of fibers and their effects on the matrix structure. Factors such as the distribution of fibers in LPM specimens, controlling microcracks and increasing the energy absorption capacity also positively affected the compressive strength performance of LPM.

For 1% and 0.5% fiber/resin ratio, the highest compressive strengths were obtained in specimens with 6%-9% T/R ratio, but in general, it is possible to say that TiO_2 ratio is not very effective on compressive strength.

3.5. Splitting tensile strength measurement

Fig. 7 shows the splitting tensile strength test results of specimens with different TiO_2/resin ratios, which vary with fiber/resin ratio. Fig. 7 shows that, as with bending strength, the marbelite specimens gave higher results in splitting tensile strength than the splitting tensile strength of white marble measured as reference. The highest strength results were obtained at 1% Fiber/Resin ratios. As expected, the increase in the fiber ratio had a direct effect on the shear forces and was the determining factor in the splitting tensile strengths. It was determined that polypropylene fibers modify the brittle structure of marble and provide a ductile behavior. This ductility improves the performance of LPM specimens under impact and loading, preventing sudden fractures and increasing energy absorption capacity. The use of TiO_2 at different ratios did not cause significant changes in the tensile strength at splitting.

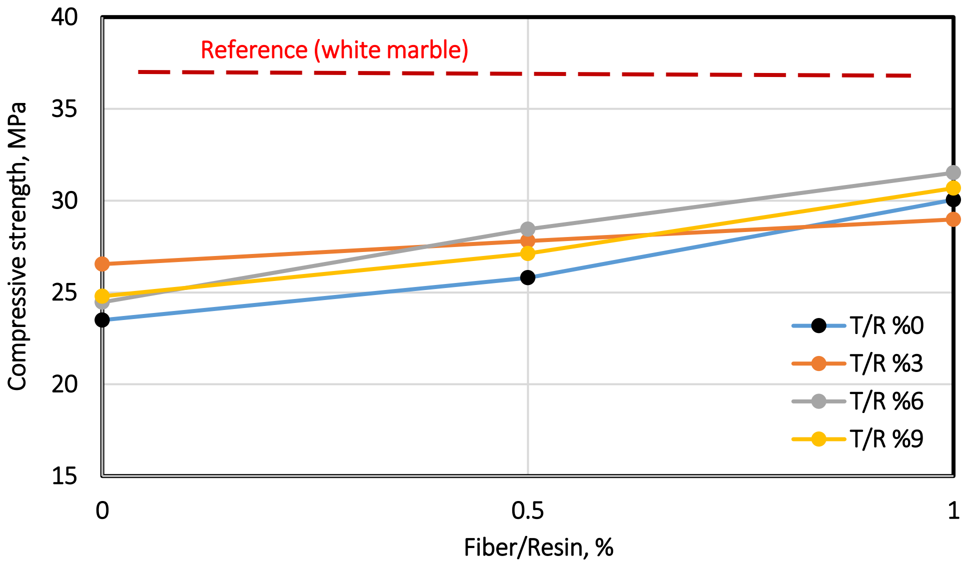

Fig. 6. Compressive strength test results of the specimens.

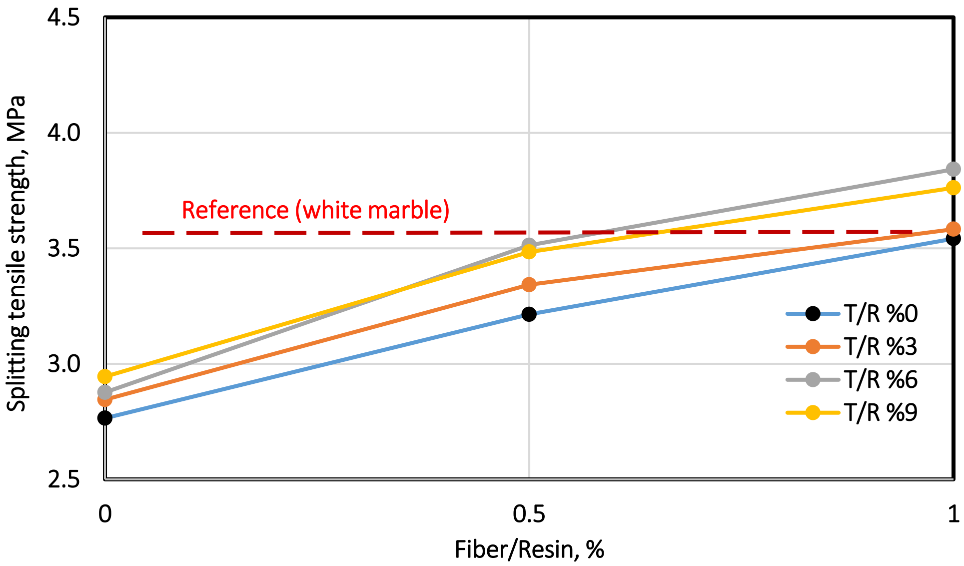

Fig. 7. Splitting tensile strength test results of the specimens.

4. Conclusions

The following conclusions were reached as a result of the tests and analysis on lightweight photocatalytic marbelite:

- In general, improvements in the mechanical properties of marbelite specimens were observed with increasing fiber ratio. When the test results were examined, the best results were obtained at a fiber/resin ratio of 1%. For bending and splitting tensile strength, LPMs had higher strengths than normal white marble. For compressive strength, the compressive strength of LPM specimens was lower than that of white marble, but strengths of up to 31.51 MPa were obtained.
- The LPM specimens, which showed very high results in the strength tests, also had better results than white marble in terms of unit weight and UPV values. In particular, the density value of 0.90 kg/dm3 shows that the LPM specimens are also superior in terms of lightness.
- It was observed that the TiO2 used for the photocatalytic properties did not cause significant changes in the mechanical properties of Marbelite. In the samples with 1% fiber/resin ratio, the best results were obtained with the use of 6% and 9% TiO2, with very small differences.

When considering the strength test results, the compressive strength of approximately 31.5 MPa, the bending strength of 12.87 MPa and the tensile strength of 3.84 MPa show that the LPM samples are quite superior in terms of mechanical strength. In particular, the fact that the bending and splitting tensile strengths are higher than those of white marble demonstrates its resistance to fracture. Unit weight and ultrasonic pulse velocity tests also showed that lighter and more homogeneous samples were obtained. Lightweight marbelite with photocatalytic properties is a promising material in the field of building materials with the results obtained in this study. When the experimental results obtained are examined, it is recommended to use 1% fiber-resin ratio in marbelite products. However, the durability of such products is also important. Therefore, it is recommended to investigate the durability of these products against chemical and thermal effects for future studies.

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Conflict of Interest

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Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

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