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Flexural behavior of reinforced concrete beams using waste marble powder towards application of sustainable concrete

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The performance of waste marble powder as a partial replacement for cement is examined with the aim to achieve more sustainable concrete. Pursuant to this goal, a total of 15 specimens were manufactured and then tested to examine the bending behavior. The effects of longitudinal reinforcement ratio and waste marble powder ratio were selected as variables. The experimental results showed that different proportions of tension reinforcement and waste marble powder had different crack and bending impacts on reinforced concrete beams. As the waste marble powder amount in the concrete mixture is increased from 0% to 40%, it was detected that the crack type changes from a shear crack from to a flexural crack as the amount of waste marble powder increases in the mixing ratio. The experimental findings revealed that the waste marble powder can be successfully used as 10% of the partial replacement of cement. Increasing the waste marble powder ratio by more than 10% can significantly decrease the capacity of the beams, especially when longitudinal reinforcement ratio is high. The influence of waste marble as partial replacement on the capacity decreases as the longitudinal reinforcement ratio decreases. Therefore, 10%–20% marble waste can be utilized as a replacement for cement when the longitudinal reinforcement ratio is close to the balanced ratio and more than 20% waste marble ratio should be avoided for any cases.

KEYWORDS

reinforced concrete, beam, waste, marble powder, recycled

1 Introduction

The continuous increase in population in the globalizing world causes a rapid decrease in limited raw material resources. For this reason, the most economical use of existing resources has become even more critical. In parallel with the discovery of new products, the amount of new waste generated is also increasing. Therefore, studies on wastes obtained from industrial raw materials in the construction sector continue (Adesina et al., 2022; Ahmad et al., 2022; Karalar et al., 2022a; Aksoylu et al., 2022; Alani et al., 2022; Arbili et al., 2022; Karalar et al., 2022b; de Azevedo A et al., 2022; de Azevedo et al., 2022; Martínez-García et al., 2022; Qaidi et al., 2022; Zeybek et al., 2022; Çelik et al., 2022). One of them is the marble wastes that occur significantly after manufacturing in marble processing factories (Basaran et al., 2022; El-Mandouh et al., 2022; Khan et al., 2022; Mangi et al., 2022; Nayak et al., 2022; Oza et al., 2022). During the extraction and processing of the marble blocks, two types of waste are generated, namely in the form of pieces and dust, and these wastes cause various adverse effects on the environment.

In Turkey, approximately 40% of the world's marble reserves are produced (Çelikten and Canbaz, 2021). However, 7 million tons of marble are processed every year in Turkey. Therefore, millions of tons of marble waste are also formed together with the finished marble (Ulubeyli and Artir, 2015). During the production of block marble, 40%–60% of the production is obtained as waste on average (Çelik, 1996; Gürer and Akbulut, 2005). Although it is impossible to store these wastes, their disposal into the environment also brings ecological problems (Alyamaç and Ince, 2009). Therefore, the recycling of these wastes has become very important. In this way, it is precious that the wastes are brought into the economy, the storage problem is reduced, and they can be reused. For this purpose, researchers investigated the suitability of substituting these wastes for cement in mortar or concrete production (Ünal and Kibici, 2001; Uygunoğlu et al., 2014). Aruntaş et al. (2010), instead of cement, concrete samples were produced by using marble dust up to 10% by weight in increments of 2.5%. In this way, they investigated the effect of waste marble dust in different proportions on the mechanical properties of concrete. As a result, they stated that waste marble dust could be safely used as a cement substitute in concrete at rates of up to 10%. Aliabdo et al. Ibrahim et al. (2014) produced concrete mixtures by substituting 5%, 7.5%, 10%, and 15% waste marble dust separately instead of sand and cement. They stated that concrete's mechanical properties improved with the material of waste marble dust. Khodabakhshian et al. (2018) produced concrete samples using 5%, 10%, and 20% waste marble dust instead of cement in their studies. As a result, they stated that using more than 10% of waste marble dust instead of cement has a negative effect on the mechanical properties of concrete. However, it was stated that mechanical properties were improved in concretes where waste marble dust was used instead of cement at 10% and lower replacement rates. Mashaly et al. (2016) produced concrete mixtures by using up to 40% marble dust instead of cement. At the end of the study, it was stated that the compressive strength of concrete increased up to 20% marble dust content, but content of waste marble dust higher than this percentage led to significant decreases in strength. Vardhan et al. (2015) conducted a series of experimental studies on the mortar obtained by substituting marble powder in different proportions instead of cement. They emphasized that the compressive strength of the mortars they produced did not change significantly with 10% waste marble dust content, and it was suitable for workability. However, it was stated that the content of marble dust higher than this rate significantly reduced the strength of the mortar.

Also, the negative effect of the addition of marble dust introduced instead of part of the cement in an amount of 10% or more is confirmed by a number of the following studies (Adesina et al., 2022; Basaran et al., 2022; Nayak et al., 2022): A decrease in the strength characteristics of concrete is noted, as well as a decrease in the workability of self-compacting concrete mixes.

As for geopolymer concretes, there is a fairly large number of experimental studies confirming the positive impact of the use of various types of stone dust on the strength characteristics of these concretes. For example, in (Mangi et al., 2022), the authors of the research found that the use of marble dust reduces the setting time of the geopolymer composite and increases its strength characteristics. In (Khan et al., 2022), according to the results of experiments, it was found that the use of various types of stone flour, including marble dust, accelerates the geopolymer reaction and increases the compressive strength by more than 10%.

With the literature research, it has been seen that there is not yet a common result concerning the rate of use of waste marble dust instead of cement. This may be due to the difference in marble cutting, waste storage, and raw material content. For this reason, it is crucial to investigate the suitability of the use of local marble waste in cement-based binders and in what proportions it can be used instead of cement. In addition, when the literature is examined, it is seen that there are very limited studies on the shear and bending behavior of reinforced concrete beams. Rajkumar et al. (2021) used by weight of cement and sand by marble powder are 20, 15, 10, 5, and 0%. They analyzed the mechanical properties such as compressive and split tensile strength for conventional and modified concretes at 7, 14, and 28 days. A total of five RC beams with dimensions 150 × 200 × 1,500 mm were cast and tested under four-point loading. The results show that marble powder can be used as an alternate construction material at lower percentage replacement levels. For this reason, in this study, tests were carried out on a small scale (100 × 150 × 1,000 mm) bending beams by substituting marble powder in different proportions for cement. The tests carried out aimed to determine the amount of marble dust suitable for use in the concrete mixture and its contribution to the concrete.

Thus, the main problem of the study is formulated. The scientific problem is the lack of a systematic knowledge base and data on structure formation, properties, and their fundamental and applied relationships between modifiers in the form of marble waste for concrete and the characteristics of reinforced concrete elements made

FIGURE 1
Marble Powder.

on the basis of such modifiers and concrete. An applied research problem is the lack of systematic data on the possibilities of recycling marble powders and marble flour as a component of concrete. The aim of the study is to establish fundamental dependencies at the micro and macro levels, as well as to determine the relationship between the structure and properties of concrete and reinforced concrete products based on them using marble powder. The objectives of the study are:

- determination of the fundamental possibility of using marble powder for environmentally friendly concrete and reinforced concrete products based on them;
- experimental determination and mathematical justification of the optimal dosages of such a modifier to obtain concrete of the highest quality structure and the highest properties;
- determination of structural and applied aspects of the manufacture of reinforced concrete products based on the obtained concrete with improved structure and properties, determination of the actual characteristics of such reinforced concrete products and structures, and determination of their practical applicability and scope.

2 Materials and methods

To ensure the verification of the data obtained and the purity of the experiment, those initial components were selected that made it possible to assess the degree and level of influence of the modifier in the form of marble powder on the properties and structure of the resulting concrete with improved characteristics and increased environmental friendliness. Methods for manufacturing samples, as well as their testing, were determined, the main raw materials mainly from those raw materials sources that are located in the Turkish region, however, allowing for assessing the degree of influence of modifiers in general.

In the experimental study, waste marble powder shown in Figure 1 was added as a replacement for cement. Amounts of 10%, 20%, 30%, and 40% of marble powder were included instead of cement. Three different longitudinal reinforcement ratio was also considered. All specimens had a stirrup spacing of 100 mm. The reinforcement layout is illustrated in Figure 2. In Figure 2, only the tension rebars change to Φ12, Φ10, and Φ8, respectively. All specimens had a dimension of 150 × 100 × 1,000 mm. The properties of the specimens are shown in Table 1. The specimens were tested under a four-point bending load, as shown in Figure 3. The shear span to effective depth was 3.1.

In order to produce the beams, CEM I 32.5 type of Portland cement was utilized. The chemical properties of this cement are given in Table 1. The water-cement ratio utilized was 0.6. Waste marble powder used in this study was obtained from the Ankara region, Turkey. Furthermore, to obtain the performance parameters of waste marble powder, a concrete pressure test was carried out. As a result of this test, these values were found 21.9 MPa for 0%, 21.4 MPa for 10%, 17.9 MPa for 20%, 13.2 MPa for 30%, and 11.5 MPa for 40% waste marble powder. The cement aggregate ratio was 0.22.

3 Empirical results and discussion

In this part of the study, the effect of different amounts of tension reinforcement and waste marble powder on the fracture and bending attitude of RCBs is obviously presented and estimated in detail. For this reason, the RCBs that are produced in the lab are tested to examine the fracture and bending attitude. As stated above, for this purpose, a total of 15 test samples were manufactured. After 15 different RCBs were prepared in the lab, these RCBs were subjected to fracture and bending tests. These fractures in the RCBs were estimated in detail and it is clearly recognized that each waste marble powder amount had a dissimilar fracture and bending influences on the RCBs. Furthermore, while performing studies; different bends were found for each RCB with dissimilar waste marble powder amounts. Each RCB had dissimilar load-carrying capabilities and these capacities are very noteworthy for the evaluation of the impact of waste marble powder amount on the fracture and bending attitude of concrete structures. In this study, 15 different RCBs were tested as shown in Table 1.

3.1 Impact of different proportions of tension reinforcement on waste marble powder

In this part, the effect of different amounts of tension reinforcement on the fracture and bending behavior of RCBs is obviously estimated in detail as follows.

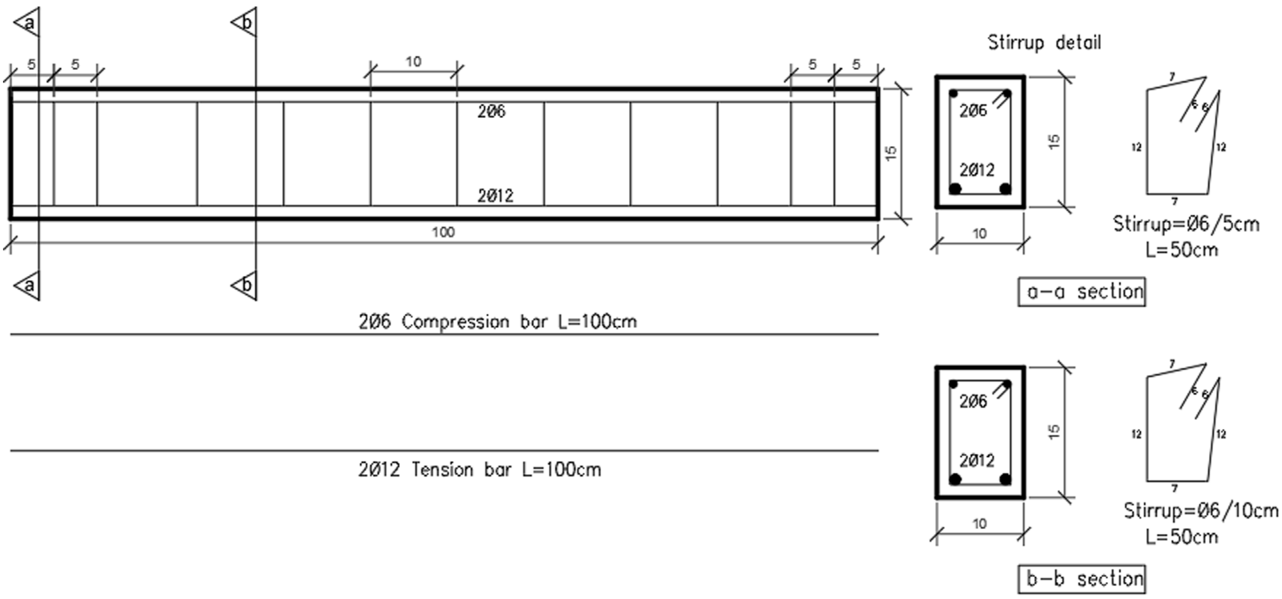

FIGURE 2
Reinforcement layout.

TABLE 1 Properties of specimens.

#	Name	Compression	Tensile	Ratio	V_f (%)
1	Φ12-M0%	2ϕ6	2ϕ12	0.0125	0
2	Φ10-M0%	2ϕ6	2ϕ10	0.0074	0
3	Φ8-M0%	2ϕ6	2ϕ8	0.0032	0
4	Φ12-M10%	2ϕ6	2ϕ12	0.0125	10
5	Φ10-M10%	2ϕ6	2ϕ10	0.0074	10
6	Φ8-M10%	2ϕ6	2ϕ8	0.0032	10
7	Φ12-M20%	2ϕ6	2ϕ12	0.0125	20
8	Φ10-M20%	2ϕ6	2ϕ10	0.0074	20
9	Φ8-M20%	2ϕ6	2ϕ8	0.0032	20
10	Φ12-M30%	2ϕ6	2ϕ12	0.0125	30
11	Φ10-M30%	2ϕ6	2ϕ10	0.0074	30
12	Φ8-M30%	2ϕ6	2ϕ8	0.0032	30
13	Φ12-M40%	2ϕ6	2ϕ12	0.0125	40
14	Φ10-M40%	2ϕ6	2ϕ10	0.0074	40
15	Φ8-M40%	2ϕ6	2ϕ8	0.0032	40

3.1.1 Case 1: Fracture and load-bending attitude of RCB (Φ12-M0%,Φ10-M0%,Φ8-M0%)

As detailed by empirical results, it is noticed that there were remarkable bending cracks in the reference RCB depending on the vertical load. Under vertical load, the maximum bending in the RCBs was measured by LVDT gadget and these bendings were clearly presented in this part as shown in Figure 4. It is presented in Figure 4 that serious cracks might be noticed in RCBs under strong loads and remarkable bending cracks are presented in Figure 4. These places of cracks are obviously presented as where vertical cracks can take place in the RCB. In addition, the maximum distance between the vertical cracks was 145 mm in the Φ8-M0% RCB (Figure 4). According to Figure 4, it is noticed that the maximum shear cracks inception from the location where the load is applied to the RCB and these cracks carry on to the bottom of RCB. To attain the numerical records about how much bending takes place in the RCB depending on vertical loads, the LVDT gadget is situated under the RCB during the test. In Figure 5, a load-displacement diagram is gained for RCBs. According to Figure 5, bending increased as a rectilinear line until an exact stage and end of this rectilinear line relates to 29.53 kN, 41.62 kN, and 65.26 kN for Φ8-M0%, Φ10-M0%, Φ12-M0%. Then, 4.28 cm, 5.51 cm, and 10.73 cm bending are noticed at maximum vertical load for Φ8-M0%, Φ10-M0%, Φ12-M0%. After these loads, though the load is reduced, the bending is considerably increased. 62.47 cm, 41.57 cm, and 30.12 cm maximum bending for Φ8-M0%, Φ10-M0%, Φ12-M0% were perceived at end of the test and RCB lost its load-carrying ability at these bending values. These results certainly display significant information about the load-carrying ability of the RCBs (Φ8-M0%, Φ10-M0%, Φ12-M0%).

3.1.2 Case 2: Fracture and load-bending attitude of RCB (Φ12-M10%,Φ10-M10%,Φ8-M10%)

As indicated by experimental results for Φ8-M10%, Φ10-M10%, and Φ12-M10%, it was noticed that there were

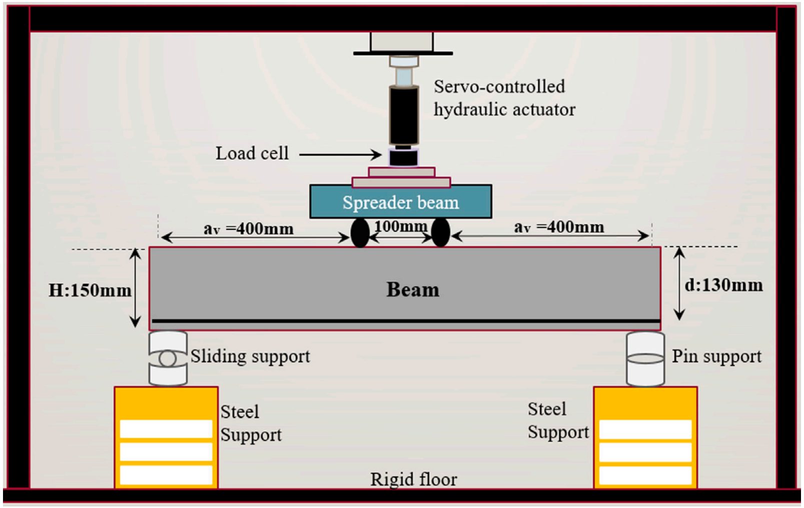

FIGURE 3
Test setup.

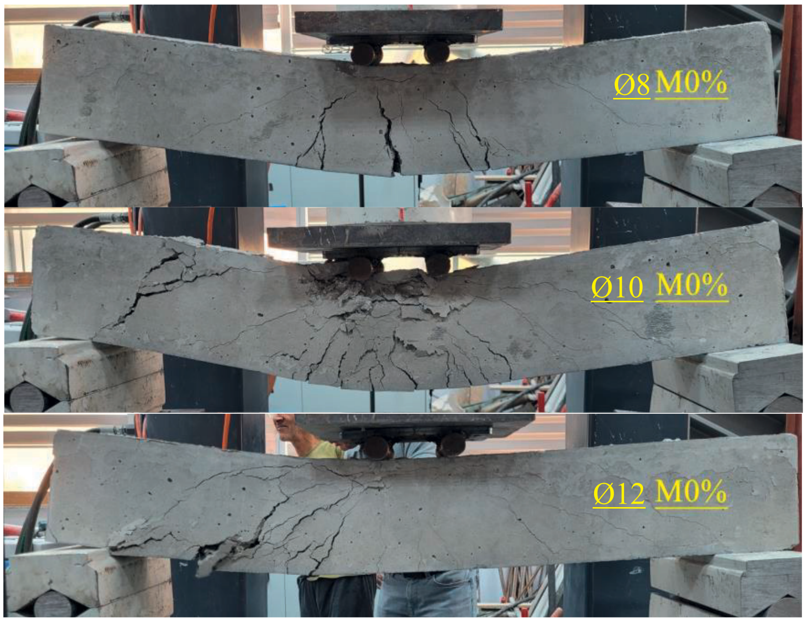

FIGURE 4
Fracture and bending attitude of RCB for Φ8-M0%, Φ10-M0%, Φ12-M0%.

noteworthy bending cracks in the RCB depending on the vertical load. As presented in Figure 6, the bendings in the RCB are identified under the vertical loads. According to Figure 6, it is recognizably offered that important cracks (vertical and shear) are noticed in the RCB. The cracking of the RCBs taking place in the bending zone depending on the vertical load is realized in Figure 6. This crushing is significant because of the impact of the defending behavior of stirrups and reinforcements on the bending behavior of RCBs. In Figure 6, significant vertical cracks are found in the middle of the RCB and these cracks are so significantly vital to estimate the crack behavior of RCBs with different amounts of tension reinforcement. As noticed in

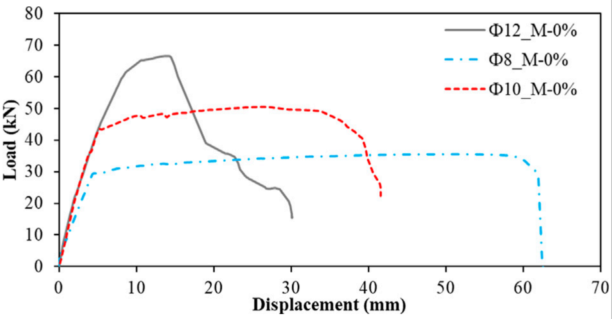

FIGURE 5
Load-Deformation attitude of RCB for Φ12-M0%, Φ10-M0%, Φ8-M0%.

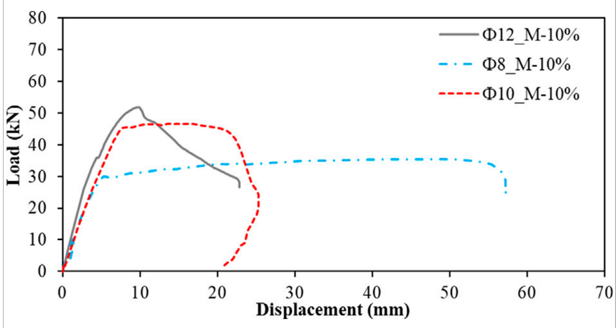

FIGURE 7
Load-Deformation attitude of RCB for Φ8-M10%, Φ10-M10%, Φ12-M10%.

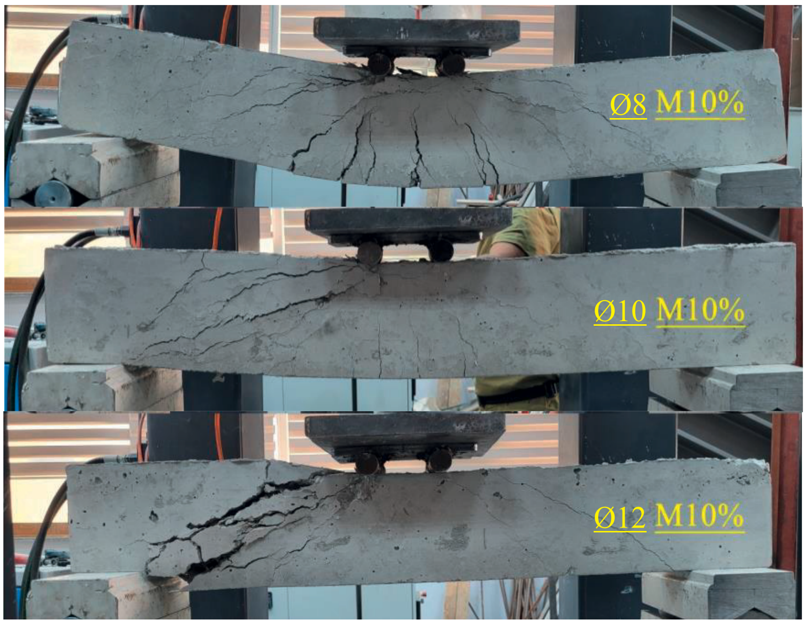

FIGURE 6
Fracture and bending attitude of RCB for Φ8-M10%, Φ10-M10%, Φ12-M10%.

Figure 7, deformations recorded by LVTD are presented clearly and this graph is very remarkable to estimate the load-bending attitude of RCB with different amounts of tension reinforcement. According to Figure 7, bendings increased as a rectilinear line until an accurate stage and end of this rectilinear line relates to 41.35 kN, 43.86 kN, and 51.84 kN for Φ8-M10%, Φ10-M10%, Φ12-M10%. Then, 6.59 cm, 7.60 cm, and 9.89 cm bending are noticed at maximum vertical load for Φ8-M10%, Φ10-M10%, and Φ12-M10%. After these loads, though the load is reduced, the bending is considerably increased. 57.21 cm, 21.14 cm, and 22.83 cm maximum bending for Φ8-M10%, Φ10-M10%, and Φ12-M10% were noticed at the ultimate of the test and RCB lost its load-carrying ability at this bending values. These results unquestionably demonstrate considerable important information about the load-carrying ability of the RCBs (Φ8-M10%, Φ10-M10%, Φ12-M10%). Additionally, these consequences appearance the impact of different amounts of tension reinforcement on the bending-load attitude of the RCB. Whereas compared RCB with different amounts of tension reinforcement, important cracks and bendings changes are noticed under the vertical load. Furthermore, less bending is noticed in the RCB for Φ10-M10%, as compared with Φ8-M10% and Φ12-M10%.

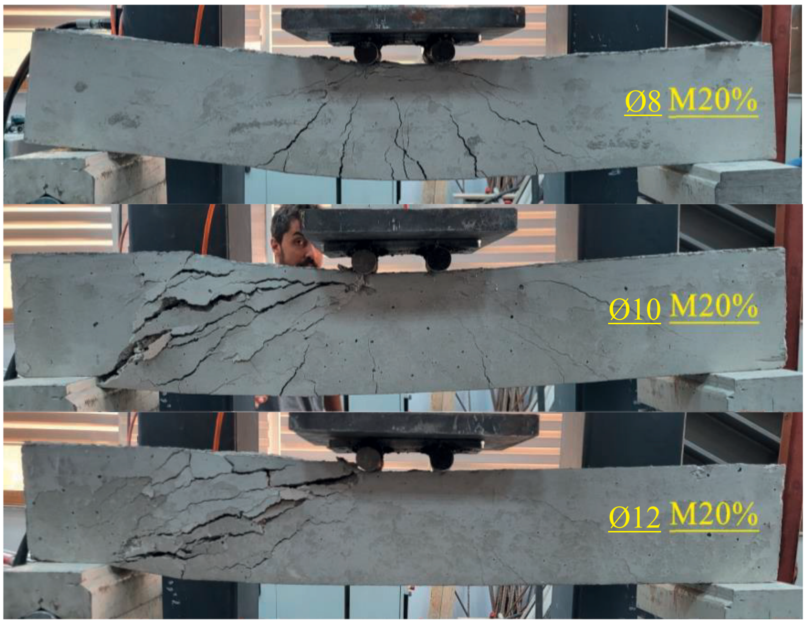

FIGURE 8
Fracture and bending attitude of RCB for Φ8-M20%, Φ10-M20%, Φ12-M20%.

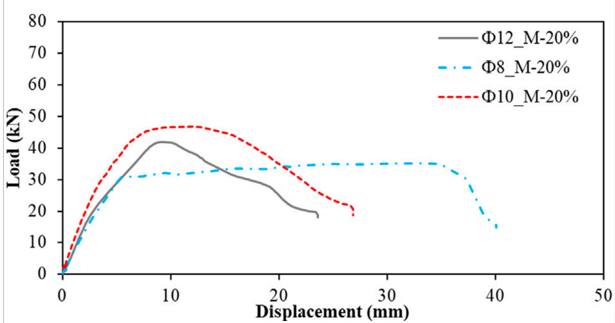

FIGURE 9
Load-Deformation attitude of RCB for Φ8-M20%, Φ10-M20%, Φ12-M20%.

3.1.3 Case 3: Fracture and load-bending attitude of RCB (Φ12-M20%,Φ10-M20%,Φ8-M20%)

As indicated by experimental results for Φ8-M20%, Φ10-M20%, Φ12-M20%, it is noticed that there were remarkable shear and bending cracks in the RCB depending on the vertical load. As presented in Figure 8, the bendings in the RCB are noticed under the vertical loads. According to Figure 8, it is recognizably offered that remarkable cracks (vertical and shear) are observed in the RCB. The cracking of the RCBs taking place in the bending zone depending on the vertical load is realized in Figure 8. According to Figure 9, bendings increased as a rectilinear line until an accurate stage and ultimate of this rectilinear line relates to 30.74 kN, 44.58 kN, and 41.81 kN for Φ8-M20%, Φ10-M20%, Φ12-M20%. Then, 5.25 cm, 7.46 cm, and 8.29 cm bending are noticed at maximum vertical load for Φ8-M20%, Φ10-M20%, and Φ12-M20%. After these loads, though the load diminished, the bending is considerably increased. Values of 40.08 cm, 26.85 cm, and 23.58 cm maximum bending for Φ8-M20%, Φ10-M20%, and Φ12-M20% were observed at the end of the test and RCB lost its load-carrying ability at this bending values. These results absolutely demonstrate considerable important information about the load-carrying ability of the RCBs (Φ8-M20%, Φ10-M20%, Φ12-M20%).

3.1.4 Case 4: Fracture and load-bending attitude of RCB (Φ12-M30%,Φ10-M30%,Φ8-M30%)

As observed by experimental results for Φ12-M30%,Φ10-M30%,Φ8-M30%, it was detected that there were significant bending cracks in the RCB depending on the vertical load as presented in Figure 10. The cracking of the RCBs occurring in the bending zone depending on the vertical load is realized in Figure 9. According to Figure 11, bendings escalated as a rectilinear line until an accurate stage and ultimate of this rectilinear line relates to 30.92 kN, 37.38 kN, and 37.65 kN for Φ8-M30%, Φ10-M30%, Φ12-M30%. Then, 5.80 cm, 9.62 cm, and 7.87 cm bending was noted at maximum vertical load for Φ8-M30%, Φ10-M30%, and Φ12-M30%. After these loads, though the load is reduced, the bending is considerably increased. When observing the results, it is observed that 38.79 cm, 20.36 cm, and 21.88 cm maximum bending for Φ8-M30%, Φ10-M30%, Φ12-M30% were noticed at ultimate of the

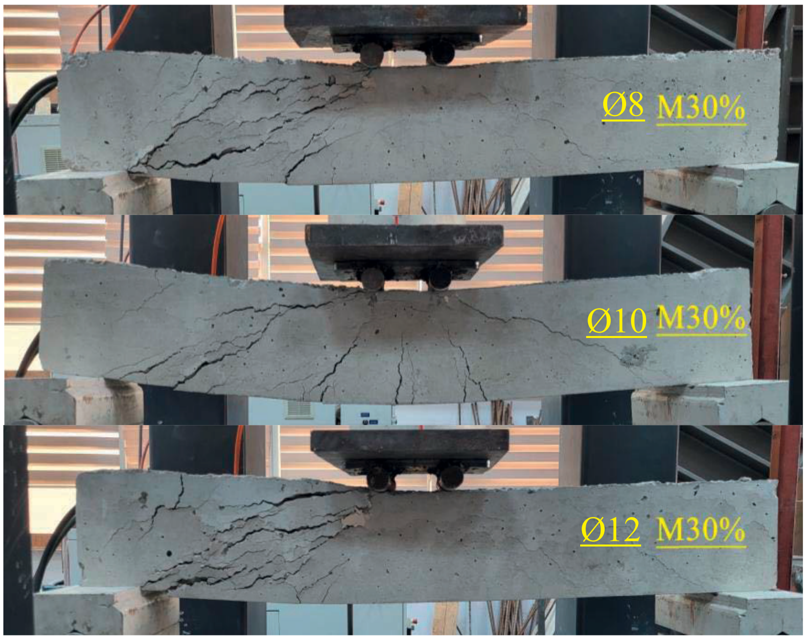

FIGURE 10
Fracture and bending attitude of RCB for Φ8-M30%, Φ10-M30%, Φ12-M30%.

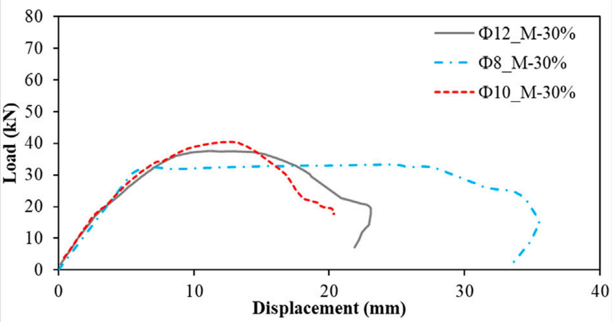

FIGURE 11
Load-Deformation attitude of RCB for Φ8-M30%, Φ10-M30%, Φ12-M30%.

test and RCB lost its load carrying ability at this bending values. In these results, it is observed that the impact of different amounts of tension reinforcement on the bending-load attitude of the RCB.

3.1.5 Case 5: Fracture and load-bending attitude of RCB (Φ12-M40%,Φ10-M40%,Φ8-M40%)

As observed by experimental results for Φ12-M40%, Φ10-M40%, and Φ8-M40%, it is noticed that there were important bending cracks in the RCB depending on the vertical load as offered in Figure 12. The cracking of the RCBs occurring in the bending zone depending on the vertical load is seen in Figure 12. According to Figure 13, bendings increased as a rectilinear line until an accurate stage and ultimate of this rectilinear line relates to 21.66 kN, 22.4 kN, and 25.32 kN for Φ8-M40%, Φ10-M40%, Φ12-M40%. At that point, 7.74 cm, 4.74 cm, and 5.34 cm of bending is observed at maximum vertical load for Φ8-M40%, Φ10-M40%, Φ12-M40%. After these loads, though the load is reduced, the bending is considerably increased. When observing the results, it is observed that 28.61 cm, 25.89 cm, and 25.43 cm maximum bending for Φ8-M40%, Φ10-M40%, and Φ12-M40% were noticed at ultimate of the test and RCB lost its load carrying ability at this bending values.

The results obtained correlate well with the results of the authors in (Çelikten and Canbaz, 2021; El-Mandouh et al., 2022).

3.2 Impact of different proportions of waste marble powder

In this part of the study, the impact of different proportions of waste marble powder on the fracture and bending attitude of RCBs is evidently examined in detail as follows.

3.2.1 Case 1: Fracture and load-bending attitude of proportion of waste marble powder for ϕ12 tension reinforcement

The effect of different proportions of waste marble powder on the fracture and bending behavior of RCBs is apparently considered. For this reason, proportions of waste marble powder are used as 0%, 10%, 20%, 30%, and 40% while tension

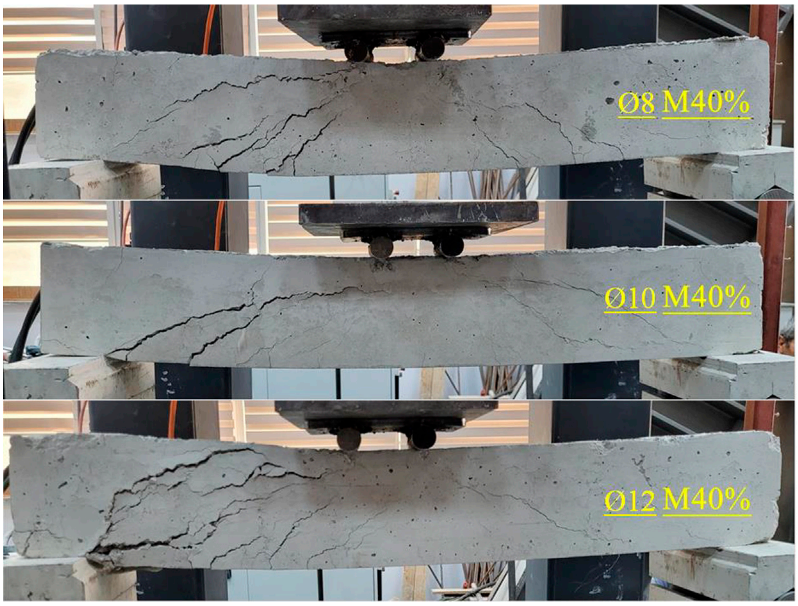

FIGURE 12
Fracture and bending attitude of RCB for Φ8-M40%, Φ10-M40%, Φ12-M40%.

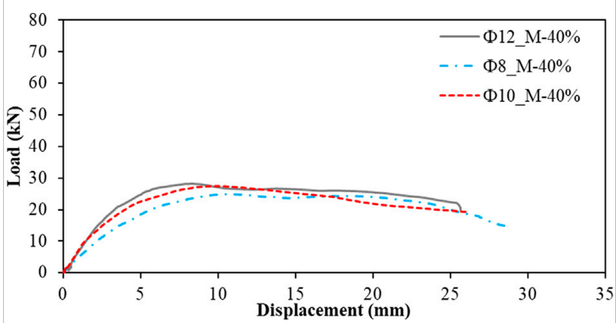

FIGURE 13
Load-Deformation attitude of RCB for Φ8-M40%, Φ10-M40%, Φ12-M40%.

reinforcement in the RCB is used constantly as 2ϕ12. As indicated by experimental results for Φ12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%, it is observed that there were noteworthy bending cracks in the RCB depending on the vertical load as shown in Figure 14. According to Figure 15, bendings escalated as a rectilinear line until an accurate stage and ultimate of this rectilinear line relates to 59.97 kN, 51.52 kN, 41.92 kN, 36.10 and 26.86 kN for Φ12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%. At that point, 8.20 cm, 9.39 cm, 8.79 cm, 8.56 cm, and 6.08 cm bending is noticed at maximum vertical load for Φ12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%. After these loads, though the load is reduced, the bending is considerably increased. When observed the results, it is observed that 30.13 cm, 22.83 cm, 23.54 cm, 22.20 cm, and 25.43 cm maximum bending for 12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40% were noticed at ultimate of the test and RCB lost its load carrying ability at these bending values. These results are indubitably important data about the load-carrying ability of the reinforcement RCBs (12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%) for different amounts of waste marble powder. As noticed from the experimental results as presented in Figure 15, for all amounts of waste marble powder used in the RCB, it is noticed that shear-type bending occurs in all RCBs.

3.2.2 Case 2: Fracture and load-bending attitude of proportion of waste marble powder for ϕ10 tension reinforcement

In this part of the examination, while tension reinforcement in the RCB is used constant as 2ϕ10, proportions of waste marble powder are changed as 0%, 10%, 20%, 30%, and 40% to investigate the impact of different proportions of waste marble powder on the fracture and bending attitude of RCBs. As comprehensive by experimental results for Φ10-M0%, Φ10-M10%, Φ10-M20%, Φ10-M30%, and Φ10-M40%, it is observed that there were significant shear and bending cracks in the RCB depending on the vertical load as shown in Figure 16. According to Figure 17, bendings increased as a rectilinear line until an accurate point and ultimate of this rectilinear line relates to 43.57 kN, 45.46 kN, 42.17 kN, 33.51 kN, and 22.4 kN for Φ10-M0%, Φ10-M10%, Φ10-

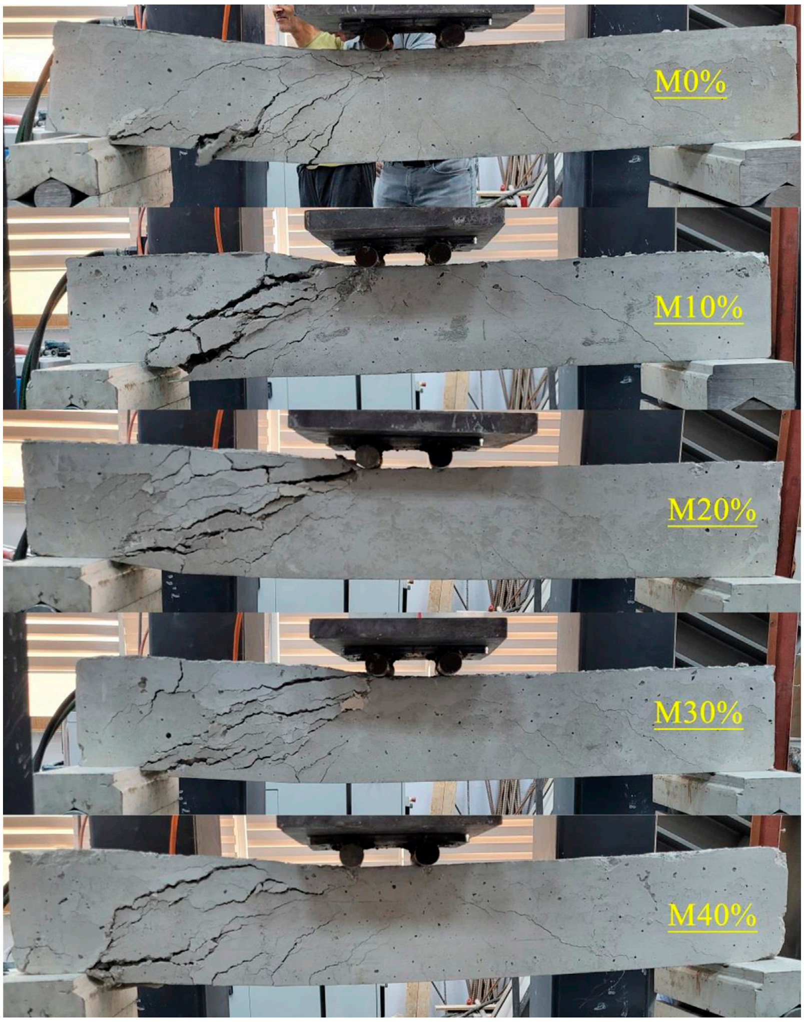

FIGURE 14
Fracture and bending attitude of RCB for Φ12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%.

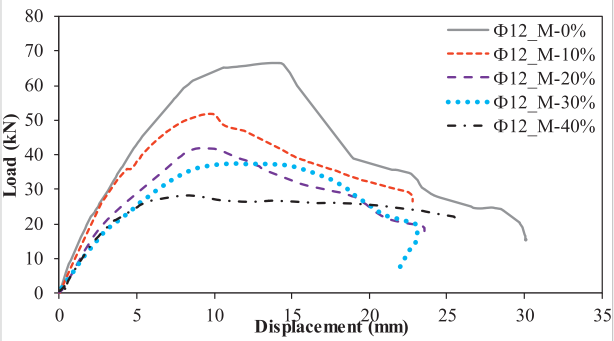

FIGURE 15
Load-Bending attitude of reference RCB for Φ12-M0%, Φ12-M10%, Φ12-M20%, Φ12-M30%, and Φ12-M40%.

M20%, Φ10-M30%, and Φ10-M40%. Then, 5.25 cm, 7.83 cm, 6.31 cm, 6.95, and 6.91 cm bending is observed at maximum vertical load for Φ10-M0%, Φ10-M10%, Φ10-M20%, Φ10-M30%, and Φ10-M40%. After these loads, though the load is reduced, the bending is considerably increased. When observing the results, it is detected that 41.57 cm, 25.06 cm, 26.85 cm, 20.08 cm, and 24.92 cm maximum bending for Φ10-M0%, Φ10-M10%, Φ10-M20%, Φ10-M30%, and Φ10-M40% were noticed at ultimate of the test and RCB lost its load carrying ability at this bending values. As noticed from the experimental results as shown in Figure 17, while amounts of waste marble powder are used as 0%, it is observed that flexural crack occurs in RCB. Additionally, it is observed that significant fractures and bendings differences are noticed under the

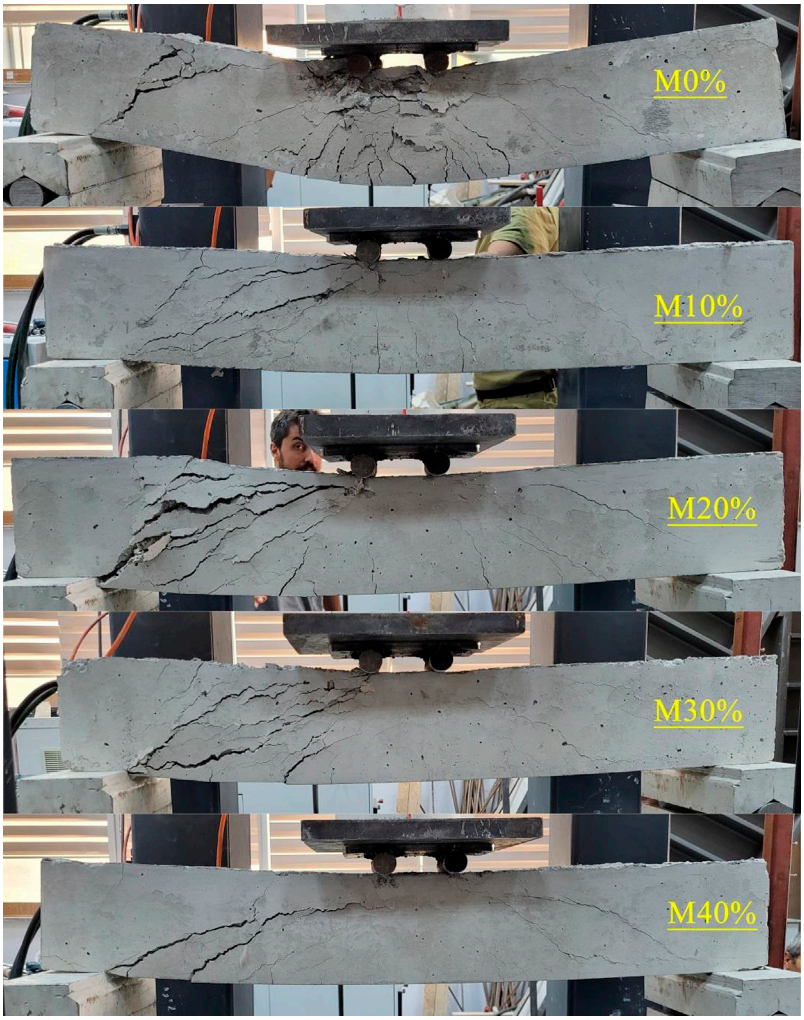

FIGURE 16
Fracture and bending attitude of RCB for Φ10-M0%, Φ10-M10%, Φ10-M20%, Φ10-M30%, and Φ10-M40%.

vertical load when compared to RCB with different amounts of waste marble powder. It is observed that the crack type changes as shear crack as the amounts of waste marble powder increase the mixing ratio. Moreover, as observed from the experimental test results, it is found that the load-displacement ability of RCB decreases as the proportion of waste marble powder is increased for all amounts.

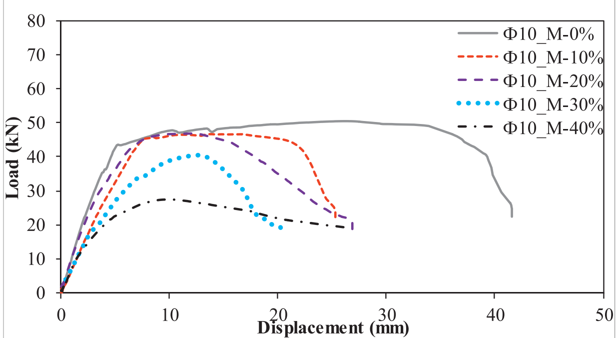

FIGURE 17
Load-Bending attitude of reference RCB for Φ10-M0%, Φ10-M10%, Φ10-M20%, Φ10-M30%, and Φ10-M40%.

3.2.3 Case 3: Fracture and load-bending attitude of waste marble powder for ϕ8 tension reinforcement

In this part of the study, while tension reinforcement in the RCB is used constant as 2ϕ8, proportions of waste marble powder are altered as 0%, 10%, 20%, 30%, and 40% to examine the effect of different amounts of waste

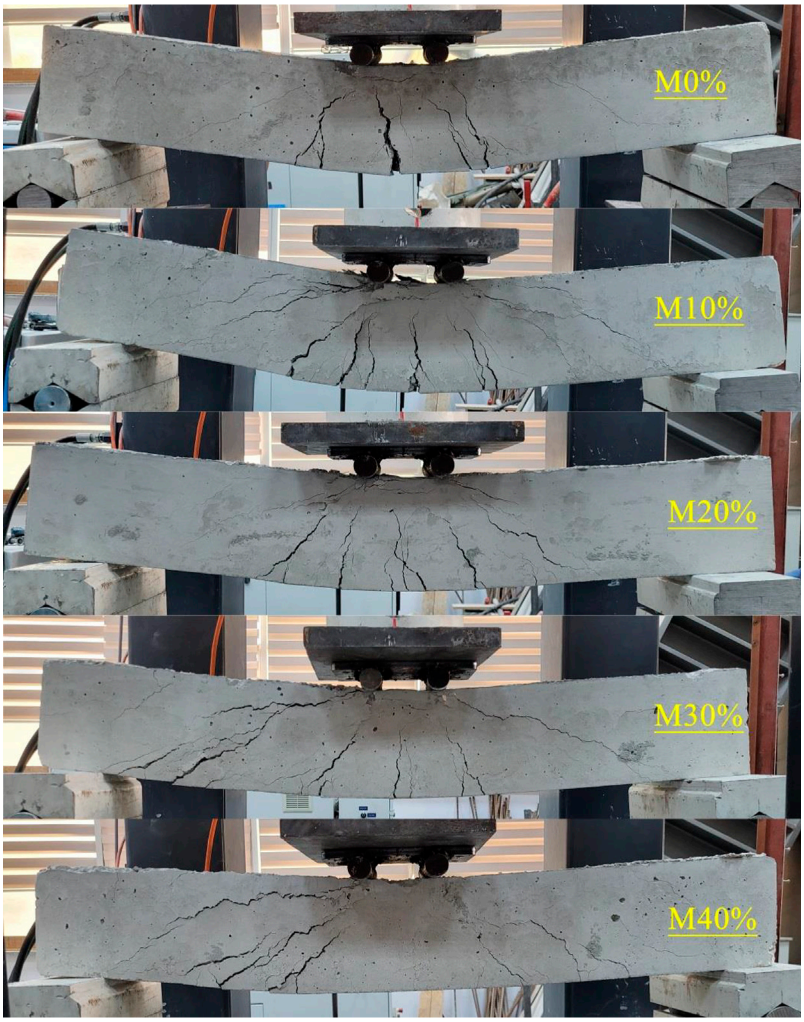

FIGURE 18
Fracture and bending attitude of RCB for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40%.

marble powder on the fracture and bending attitude of RCBs. As comprehensive by experimental results for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40%, it is detected that there were noteworthy shear and bending cracks in the RCB depending on the vertical load as shown in Figure 18. According to Figure 19, bendings increased as a rectilinear line until an accurate point and ultimate of this rectilinear line relates to 28.91 kN, 31.41 kN, 31.92 kN, 33.51 kN, 31.41 kN and 22.21 kN for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40%. Then, 4.97 cm, 5.8 cm, 6.12 cm, 5.80 cm, and 5.09 cm bending is observed at maximum vertical load for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40%. After these loads, though the load is reduced, the bending is considerably increased. When observing the results, it is detected that 62.47 cm, 57.21 cm, 40.08 cm, 33.68 cm, and 27.96 cm maximum bending for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40% were observed at ultimate of the test and RCB lost its load carrying ability at this bending values. Furthermore, it is detected that significant fractures and bendings differences are noticed under the vertical load while comparing RCB with different amounts of waste marble powder. It is detected that the crack type changes from shear crack to flexural crack as the amounts of waste marble powder increase in the mix ratio. The reason behind it that as the inclination of the waste marble powder amount increases, the load capacity of the beams decreases, and the failure mode changes from flexure to shear even though the mechanical properties of the concrete, main, and shear reinforcement ratio are the same with the corresponding beams. Moreover, as observed from the experimental test

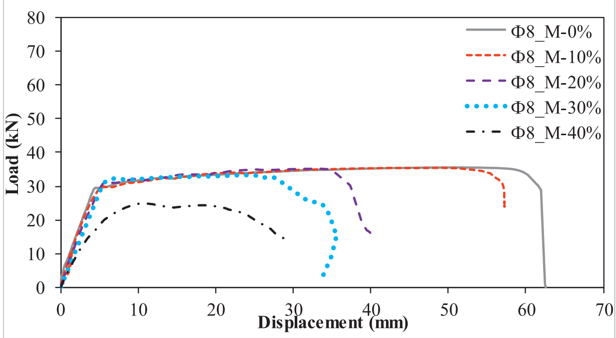

FIGURE 19
Load-Bending attitude of reference RCB for Φ8-M0%, Φ8-M10%, Φ8-M20%, Φ8-M30%, and Φ8-M40%.

results, it is found that the load-displacement ability of RCB decreases as the proportion of waste marble powder increases for all amounts.

4 Conclusion

In this study, experimental tests considered the bending-load behavior and crack behavior of various RCBs produced with waste marble powder. Three of these specimens were reference specimens without any waste marble powder, while the others consisted of V_f amounts of 10%, 20%, 30%, and 40% waste marble powder. After RCBs are prepared in the lab, these special RCBs are exposed to crack tests using a special device. Crack and bending behaviors of the RCBs are assessed according to the experimental tests in detail. These important results are evaluated below:

- According to slump test results, it is recognized that as the waste marble powder amount in the concrete mixture is increased, it is observed that there is a decrease in the compressive strength value of concrete.
- According to experimental test results, it can be indicated that the maximum load-carrying value in the RCBs decreases when the proportion of waste marble powder in the concrete mixture increases. Once reinforcement RCBs with different waste marble powder amounts are compared with each other, maximum bending in the middle of the RCB is observed for Φ8-M10%, waste marble powder RCBs.
- It is speciously recognized that the waste marble powder amount significantly affects the crack behavior of the RCBs. Significant vertical and bending cracks are noticed in the RCBs depending on waste marble powder. As the waste marble powder amount in the concrete mixture is increased from 0% to 40%, it is detected that the crack type changes as a shear crack from the flexural crack as the amounts of waste marble powder increase the mixing ratio.
- In this study, the effect of different amounts of tension reinforcement on the crack and bending behavior of RCBs is considered in detail. As observed from the experimental results, for all amounts of waste marble powder used in the RCB, it is noticed that flexural crack occurs in RCBs using 2ϕ8 tension reinforcement. For other sections, shear cracks occur in RCBs.

To surmise, 10% waste marble as a replacement for cement is recommended for overall performance. This ratio can be slightly increased to between 10%–20% waste marble when the longitudinal reinforcement ratio decreases. More than 20% of waste marble should be avoided as a partial replacement for cement.

In future studies, we aim to obtain a mathematical formula to describe the load-deflection curves depending on changes in marble waste utilizing statistical analysis and artificial intelligence studies.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

Conceptualization, YOÖ and MK; methodology, YOÖ and CA; data curation, YOÖ; investigation, YOÖ. Writing-original draft preparation, YOÖ, MK, CA, AB, SS, ES, and MMSS; writing-review and editing, YOÖ, MK, CA, AB, SS, ES, and MMSS; funding acquisition, MMSS. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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