Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **21** (2021) 055601 (1137-1145) AKU J. Sci. Eng. **21** (2021) 055601 (1137-1145)

DOI: 10.35414/akufemubid.977280

Araştırma Makalesi / Research Article

The Effect of Marble Powder and Fly Ash on Mechanical Properties of Cement Mortars

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Geliş Tarihi: 01.08.2021 Kabul Tarihi: 30.10.2021

Keywords
Marble Powder;
Fly ash;
Cement Mortar;
Mechanical Properties

Abstract

Marble powder and fly ash have a significant influence on building technology. Fly ash and marble powder allow the production of cement-based composites with different properties. The use of marble powder and fly ash in mortars was researched and the findings of the study to understand the effect of these materials on mortar were presented. The fine aggregate was substituted with marble powder, fly ash, and both marble powder and fly ash in a total of 15 mortar mix produced with CEM I 42.5 R cement. 7 and 28 days bending and compression tests were applied to the samples produced with a constant (0.58) water/cement ratio. The microstructure of the samples was investigated by XRD technique. In the substitution of standard sand with marble powder, it was discovered that a 5% substitution increased flexural and compressive strength. Similarly, 20% fly ash substitution in mortars resulted in maximum mechanical properties, with a compressive strength of 49.5 MPa. It was also determined that using 15% marble powder and 15% fly ash increased the mechanical properties of mortars. It has been concluded that fly ash is a very effective additive in mortar thanks to its pozzolanic properties, and the use of fly ash and marble dust in cement-based composites is an important application to protect the environment.

Mermer Tozu ve Uçucu Külün Çimento Harçlarının Mekanik Özelliklerine Etkisi

Anahtar Kelimeler
Mermer Tozu;
Uçucu Kül;
Çimento Harcı;
Mekanik Özellikler

Öz

Mermer tozu ve uçucu kül, yapı teknolojisi üzerinde önemli bir etkiye sahiptir. Uçucu kül ve mermer tozu, farklı özelliklerde çimento esaslı kompozitlerin üretilmesine olanak sağlar. Bu çalışmada, harçlarda mermer tozu ve uçucu kül kullanımı incelenmiş ve bu malzemelerin harcın mukavemet özellikleri üzerindeki etkisini belirleyen çalışmanın sonuçları sunulmuştur. Çalışmada CEM I 42.5 R çimentosu ile ince agreganın mermer tozu, uçucu kül ve uçucu kül ile birlikte mermer tozu ikame edildiği toplam 15 harç karışımı üretilmiştir. Sabit (0.58) su/çimento oranıyla üretilen numunelere 7 ve 28 günlük eğilme ve basınç testleri uygulanmıştır. Numunelerin mikro yapısı XRD tekniği ile incelenmiştir. Mermer tozunun standart kum ile %5 oranında ikame edilmesi basınç ve eğilme dayanımını arttırdığı belirlenmiştir. Ayrıca, %20 uçucu kül ikamesi, harçlarda 49.5 MPa basınç mukavemeti elde edilerek en yüksek mekanik özellikler bulunmuştur. Benzer şekilde, %15 mermer tozu ve %15 uçucu kül kullanımının harçların mekanik özelliklerini iyileştirdiği tespit edilmiştir. Uçucu külün puzolanik özelliklerinin sayesinde harçta oldukça etkili bir katkı malzemesi olduğu ve uçucu kül ile mermer tozunun çimento esaslı kompozitlerde kullanımı çevreyi korumak için önemli uygulama olduğu sonucuna varılmıştır.

1. Introduction

Rapid population growth and technological innovations increase the amount and diversity of industrial, mining, domestic, and agricultural sourced solid wastes (Dhanapandian *et al*. 2009). Community policy on waste management is based on minimizing waste generation by reducing waste generation, but promoting recycling and reusing waste through clean technologies is the best way to reduce pollution caused by waste (Eliche-Quesada *et al*. 2012).

Since the use of thermal power plants for power generation, millions of tons of fly ash (FA) and related by-products have been released. Annual FA production is approximately 800 million tons which are expected to be increased in the future (Golewski 2020). Storage of FA in waste sites is the first option for many countries. However, the elements and components of FA increase the potential of the FA to be recovered as raw materials. In this way, in addition to the benefits of waste disposal and conservation of natural resources, it contributes to the use of low-cost raw materials (Ferreira *et al*. 2003).

Fine-sized marble wastes can be easily dispersed by the effect of wind and mixed with soil with the impact of rain and snow. Thus, fine-sized marble wastes cause more pollution than other marble wastes. Exposing particles smaller than 2 mm when cutting marble blocks is an essential problem for the marble industry. When 1 m^3 marble block is cut into 2 cm thick slabs, the marble powder (MP) is 25% of the total waste amount (Bilgin *et al*. 2012).

Hwang et al. (1998) investigated a study on strength development in fine aggregate 25% and 45% FA substituted mortar samples resulted in increased flexural and compressive strength and increased resistance to carbonation shrinkage.

Mangaraj and Krishnamoorthy (1994) examined the ratio of 0% to 30% FA substitution with fine aggregate for mortar samples with a water/cement ratio of 0.60, an increase in compressive strength was achieved.

Pofale and Deo (2010) determined in their study that the substitution of sand with 27% of the FA increases the compressive strength by about 20% and the flexural strength by 15%. In this study, fly ash-based portland pozzolan cement was used. Also, it has been determined that fly ash-based concrete has an approximately 25% increase in workability compared to reference concrete.

Maslehuddin (1989) examined concretes produced by fine aggregate by substitution of 0%, 20%, and 30% with FA. FA substitution in the concrete mixture increased early wet compressive strength and long-term corrosion resistance properties.

Bonavetti and Irassar (1994) observed that the use of fine aggregate 5% and 20% MP in mortar mixtures prepared in water/cement 0.48 ratio increases the pressure and flexural strengths at an early age. The 28-day strength of the mortar up to 20% substitution of MP showed strength similar to the reference sample. In mortars with MP substitution rates of 5% and 10%, an increase in strength values of 28 days was recorded.

Keleştemur et al. (2014) found that partial substitution of fine aggregate with MP increases the compressive strength of the mortar. Strength increase has been linked to the filler effect and the improvement in the transition zone. In addition, the flexural strength of glass fiber reinforced mortar increased with the substitution of MP.

Almeida et al. (2007) determined that the 7 and 28 days compressive strength of fine aggregate samples with 5% MP substitution was higher than the reference sample compressive strength. This increase in strength has been linked to the improvement in hydration and the micro filler effect caused by MP.

Rai et al. (2011) examined the mechanical properties of concretes that fine aggregate was substituted with MP at the rates of 5%, 10%, 15%, and 20%. Compared to the reference sample, 28 days of compressive strength of 20% substituted sample is decreased slightly. It has been determined that the 15% substitution of MP increases the flexural strength by 25% and, at higher rates, reduces the flexural strength. In this study, the effect of marble powder and fly ash on the mechanical properties of cement mortars were investigated.

2. Material and Method

2.1 Materials

CEM I 42.5 R portland cement produced by Afyon Cement Industry was used as a binder material in the prepared cement pastes. The chemical properties of CEM I 42.5 R cement in accordance with EN 197-1 standard are given in Table 1.

Table 1. CEM I 42.5 R portland cement chemical properties.

Constituent	Value (%)	EN 197-1
SO_3	2.91	<3.5
MgO	2.33	<5.0
LOI	1.92	<4.0
Cl	0.06	<0.1
Insoluble matter	0.67	<1.5

Rilem Cembureau (CEN) standard sand in accordance with EN 196-1 standard is used. Standard sand was supplied from Trakya Cement Factory. The grain size analysis of the standard sand is given in Figure 1. Accordingly, d_{20} = 0.32 mm, d_{50} = 0.75 mm, d_{80} = 1.35mm and d_{max} = 2mm.

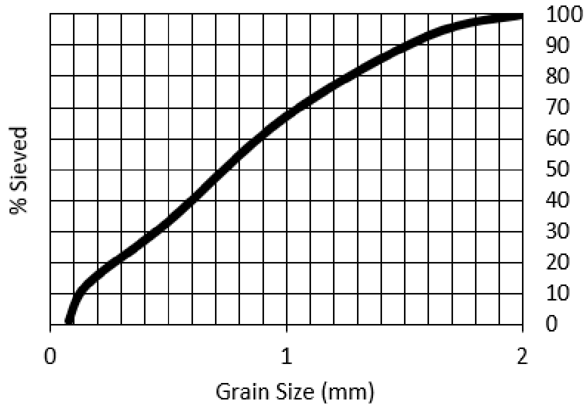

Figure 1. Grain size analysis of standard sand.

The total amount of silicon dioxide, aluminum oxide, ferric oxide (SAF) of FA used in mortar samples is 88.21%, it is in class F, and the 28-day pozzolanic activity index of the FA was determined 72.5%. FA chemical properties are presented in Table 2.

Table 2. Chemical composition of fly ash and marble powder.

Constituent	Fly ash (%)	Marble powder (%)
SiO_2	56.020	0.200
Al_2O_3	22.380	0.120
Fe_2O_3	9.810	0.050
CaO	2.100	55.030
MgO	3.720	0.390
Na_2O	0.180	0.050
P_2O_5	0.220	0.030
K_2O	2.050	0.010
TiO_2	1.000	-
SO_3	0.560	-
$SiO_2+Al_2O_3+Fe_2O_3$	88.210	0.370
Loss of ignition	1.010	-

MP obtained in Afyonkarahisar region and MP chemical properties used in the samples are presented in Table 2. Accordingly, MP contains 55% CaO as major oxide, and loss of ignition has 43.7%. The loss of ignition is largely due to the CO_2 released during the calcination of $CaCO_3$. FA and MP, grain size analysis, is presented in Figure 2. In MP, d_{50} = 0.007 mm and d_{90} = 0.060 mm, while in FA, d_{50} = 0.045 mm and d_{90} = 0.130 mm (Figure 2).

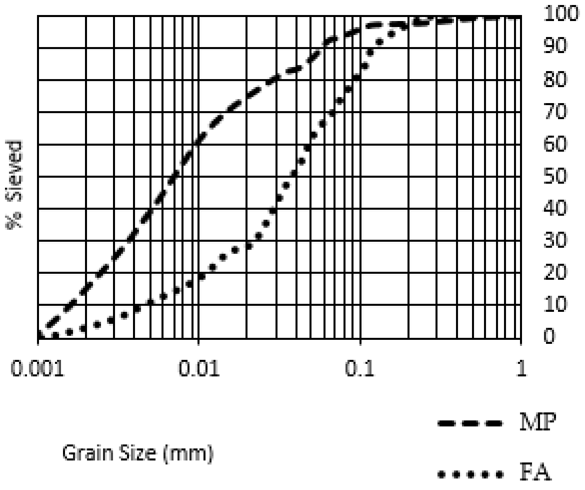

Figure 2. Grain size distribution of MP and FA.

2.2 Preparation of mixtures

Mixtures were prepared in 3 series: MP series (marble powder), FA series (fly ash), and MU series (marble powder and fly ash). In the MP series, standard sand is substituted by 0% (reference sample) 5%, 10%, 20%, 30%, 40% and 50% MP by weight. In the FA series, standard sand is substituted by 5%, 10%, 20%, and 30% FA by weight. In the MU series, standard sand was substituted by MP and FA in equal proportions of 2.5%, 5%, 10%, 15% by weight (Table 3). In all series, the water/cement ratio is kept constant as 0.58, and 900 gr of cement was used. MP substitution rates were chosen higher since MP is an industrial waste and causes environmental problems.

Table 3. Substitution amount of sand, MP, and FA by weight.

Sample	Sand (g)	MP (g)	FA (g)
Reference	2700	—	—
MP5	2565	135	—
MP10	2430	270	—
MP20	2160	540	—
MP30	1890	810	—
MP40	1620	1080	—
MP50	1350	1350	—
FA5	2565	—	135
FA10	2430	—	270
FA20	2160	—	540
FA30	1890	—	810
MU2.5	2565	67	67
MU5	2430	135	135
MU10	2160	270	270
MU15	1890	405	405

All materials were prepared by weighing separately on the sensitive scale according to the determined ratios. The prepared materials were placed in the mixer for mixing. Firstly, water and cement were added to the mixing bowl, respectively, and mixed for 20-30 seconds to obtain cement paste. Then, standard sand, MP, or FA was added and mixed for approximately 2-3 minutes until homogeneity was achieved and poured into prismatic moulds with dimensions of 40x40x160 mm and compressed using the vibrating table (Figure 3). After 24 hours of production, the moulds were removed, and the samples were placed in the curing tank at 20°C.

Figure 3. Sample mold process.

3. Results

3.1 Flexural and compressive strength

The three-point flexural strength test was performed on prism mortar samples of 40x40x160 mm cured 7 and 28 days in the curing pool. In the experiments, a standard cement press with 20 tons compressing and 2 tons flexural capacity was used. The compressive strength test was carried out on samples obtained from the flexural strength test.

The highest flexural strength value in MP series was obtained in MP5 series with 5% MP substitution. The flexural strength was obtained higher than the reference sample in all series with MP substitution. FA substitution in mortars increased the flexural strength of mortars. The flexural strength of the samples for 28 days is 6%, 16.6%, 25%, and 14.2% percent increase was achieved according to the reference sample. It is considered that the increase in strength in the FA doped series is due to the pozzolanic property of the fly ash, leading to an increase in strength with secondary reactions (Figure 4).

In the MU series, 10% MP and 10% FA substituted MU10 samples provided the highest 28-day flexural strength. Flexural strength increased up to 10% substitution rate and decreased 15% substitution rate (Figure 4). MP series was determined to be the highest 7 and 28 days compressive strength MP5 sample. Compressive strength increased with the micro-filling effect of MP. However, the higher surface area and internal friction of MP at higher substitution rates reduced workability and resulted in a decrease in compressive strength (Figure 5).

With the increase of FA substitution in the FA series, an increase in compressive strength was achieved. The highest strength increase was obtained in the series containing 20% FA. According to the reference sample, 28-day compressive strength values are increased by 10.6%, 9.6%, 56.2%, and 39.55%, respectively. The occurrence of pozzolanic reactions at older ages increased the compressive strength for 28 days. In addition, the substitution of the sand with the FA provided an increase in 7-day compressive strength (Figure 5).

Compressive strength decreased in MU2.5 and MU5 series compared to the reference sample. MU10 and MU15 samples have 6.9% and 7% higher 28 days compressive strength than the reference sample. It is evaluated that the increase in the amount of FA in the mixture improves the strength with the pozzolanic effect.

3.2 X-ray diffraction

The reference sample, MP20, MP40, MP50, FA20, and MU10 samples were selected by considering the mixture ratios, flexural, and compressive strength values for mineralogical analysis with the XRD qualitative method of cement paste mixtures. Ettringite, portlandite, quartz, calcium carbonate, C_3S, C_2S, and C-S-H were detected in the XRD analyses. Patterns of XRD analyses and the crystal phases in the samples are given in Figure 6.

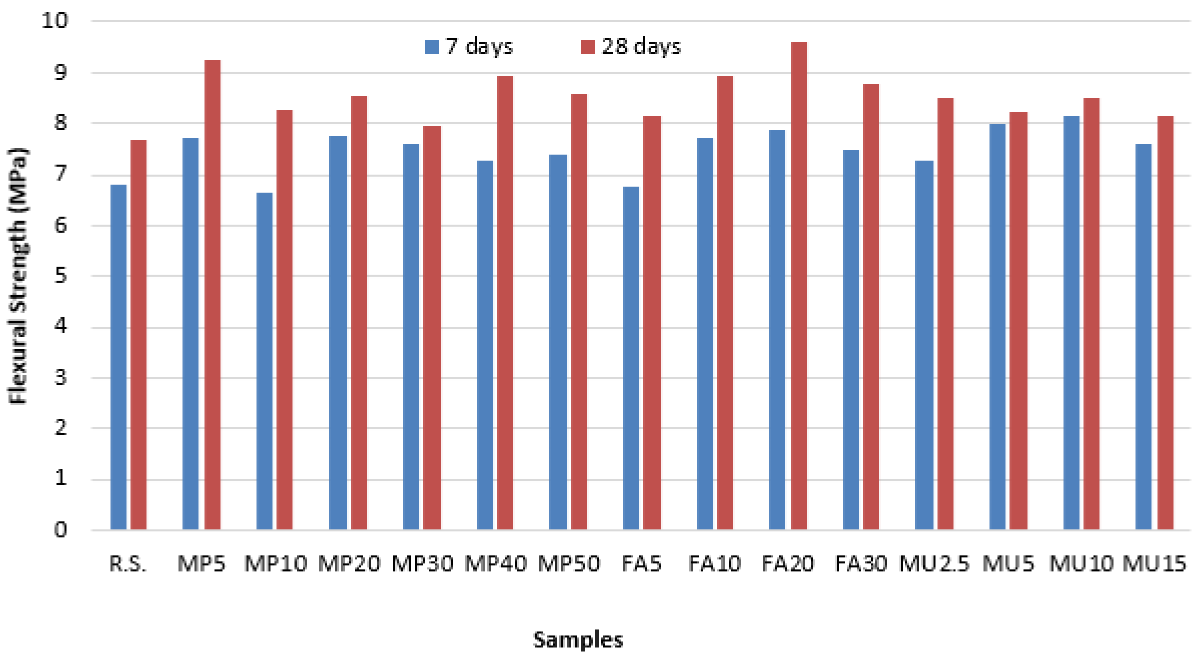

Figure 4. The 7 and 28 days flexural strength.

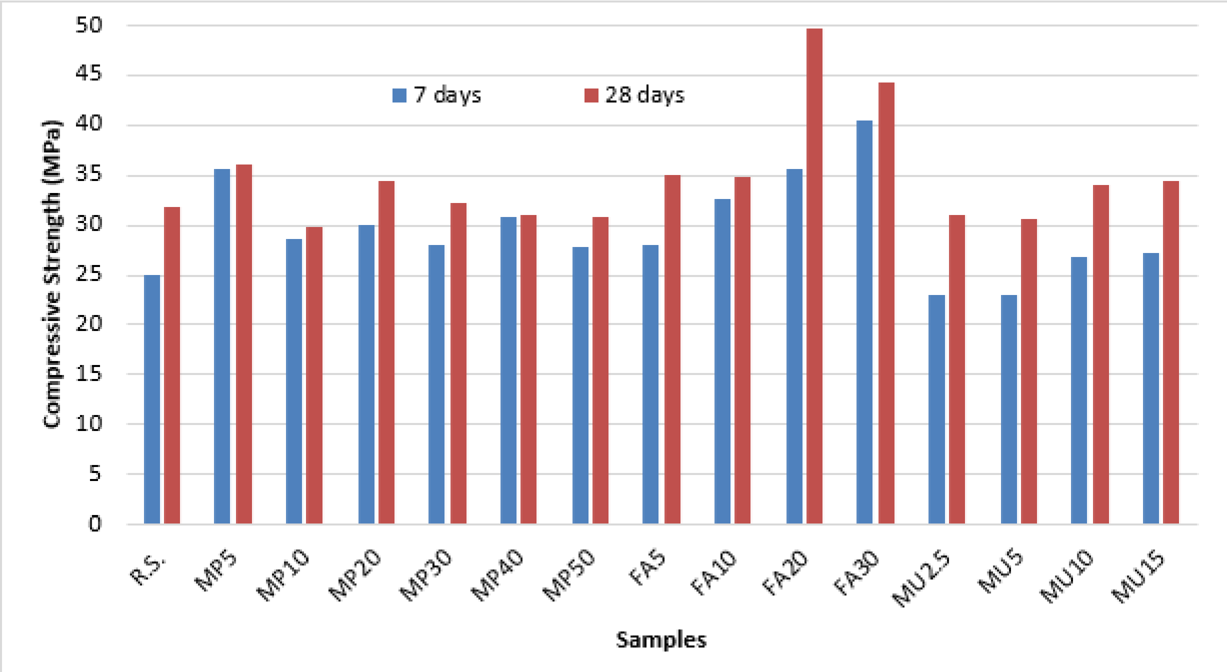

Figure 5. The 7 and 28 days compressive strength.

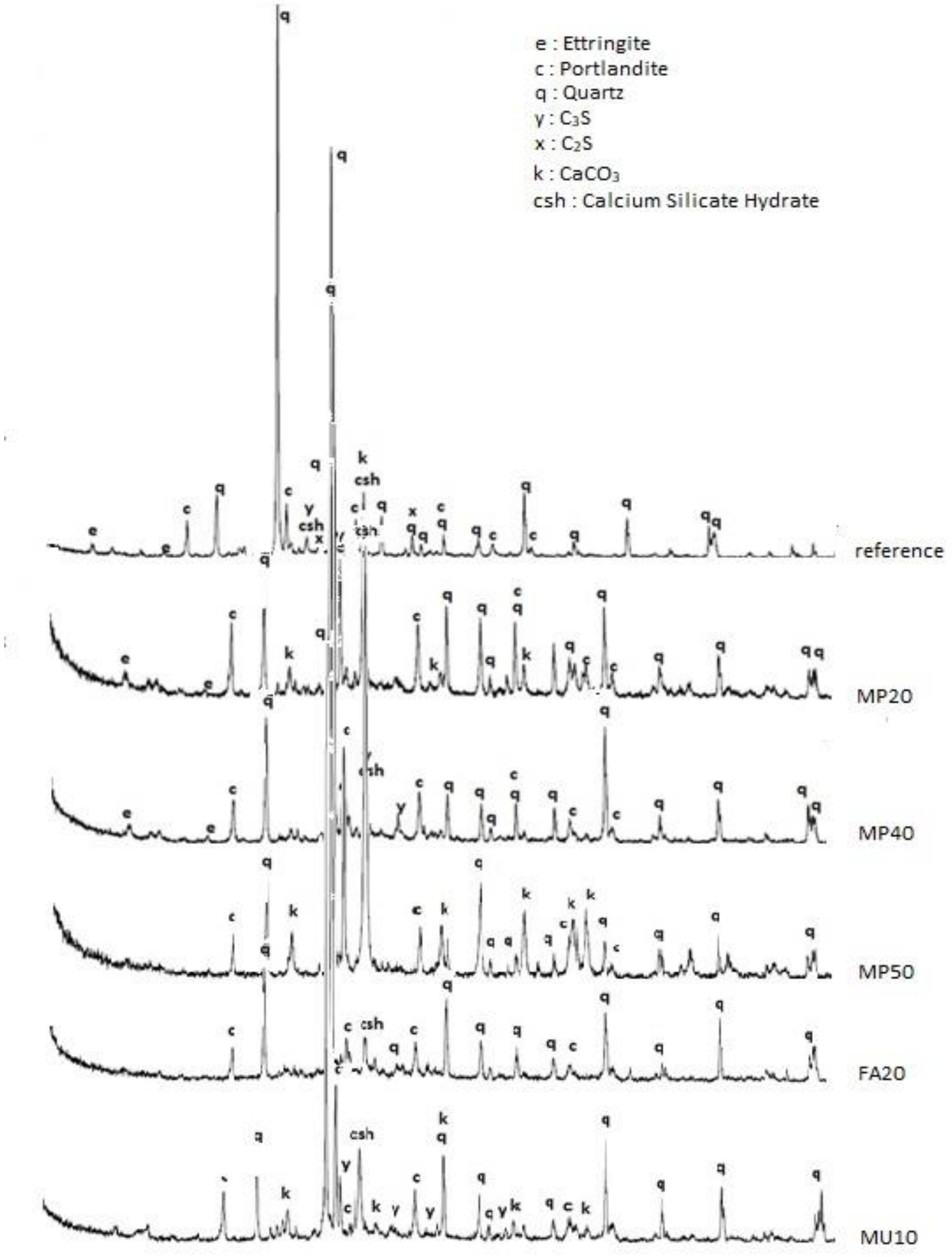

Figure 6. XRD analyses of selected samples.

In the XRD analysis of cement paste mixtures, generally the quartz, calcium carbonate and C-S-H intensity increased as the MP substitution rate increased (Figure 6).

4. Conclusions

Samples were produced by substitution marble powder and fly ash with fine aggregate in certain proportions. Physical and mechanical tests were carried out on the samples, microstructure properties were examined. The flexural and compressive strength values of mortars produced using MP have increased compared to the reference sample. Accordingly, the highest flexural and compressive strength values were obtained in samples with 5% MP substitution. As a reason, it is thought that 5% MP has a microfill effect and increases the adherence to the interface. The fine aggregate surface area has increased greatly, and the workability has decreased in substitutes with mortars over 10%. Although the rate of substitution increases in mixtures of 10% or more compared to the reference sample, it is considered that this is due to the fact that the fine grains fill the void structure and increase the composition (occupancy) of the mortar.

The use of FA has increased the strength of mortars with its pozzolanic effect. With the substitution of the FA by 20%, the compressive strength increased by 56.2% was achieved compared to the reference sample. Substitution of fine aggregate with F class FA in mortars increased the amount of C-S-H gels as a result of pozzolanic reactions and improved the mechanical properties of the mortar.

In mortars where MP and FA are used together, strength values are higher than the reference (MU10, MU15). Accordingly, with the use of FA and MP, it will be possible to produce higher performance mortars and also using more amount waste mineral materials.

Although the sample with an MP substitution rate of 5% offers optimum strength values, FA provides high strength at high substitution rates due to its pozzolanic feature.

In the study, the effect of marble powder, which is an industrial waste produced at a large scale in Afyonkarahisar region, on cement mortars was investigated. As a result, it has been determined that using marble powder with fly ash in certain proportions improves the mechanical properties of mortars and enables an environmentally friendly and sustainable production.

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