Some Engineering Properties of Natural Building Stones of Cyprus

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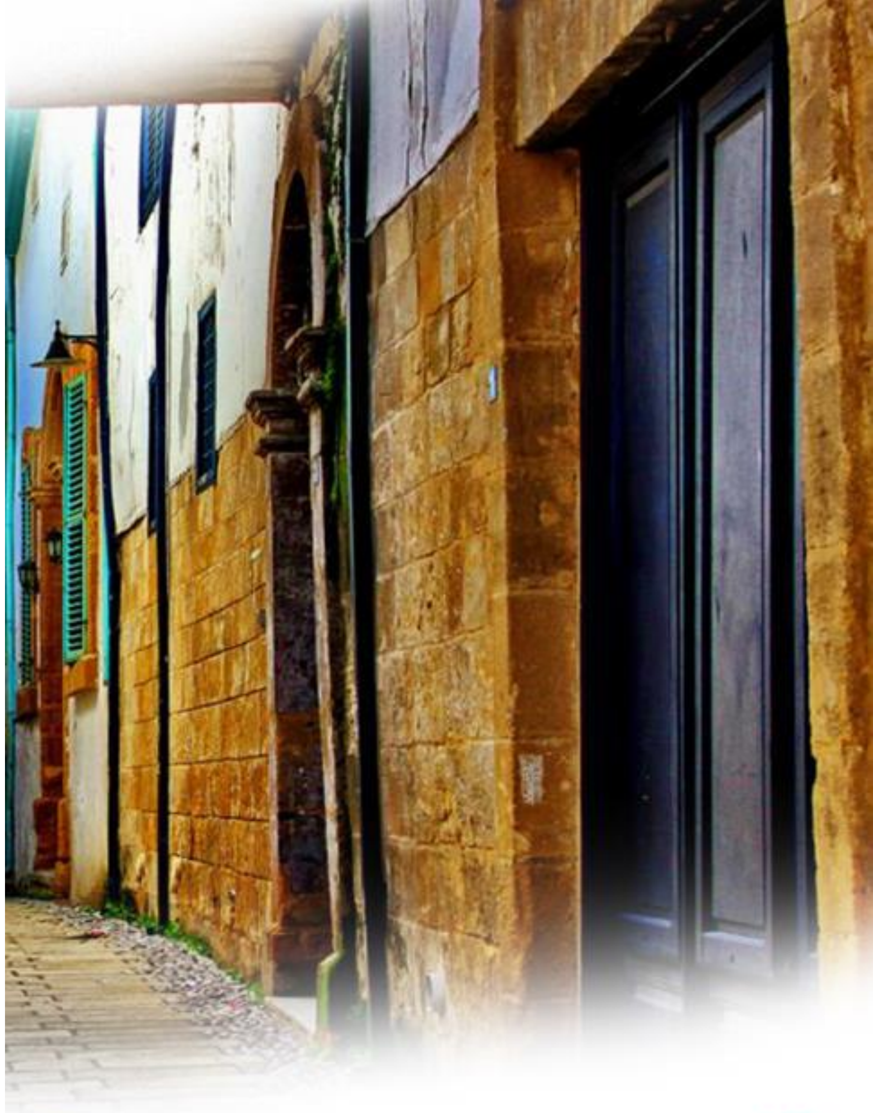

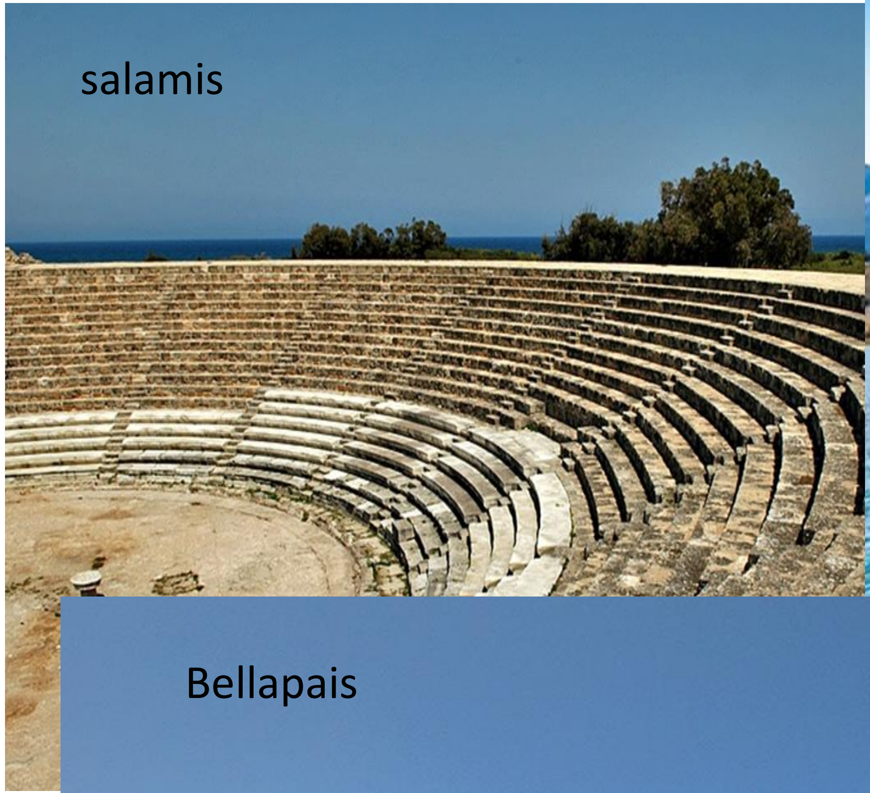
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ABSTRACT

Natural building cut stones are being used in Cyprus for ages to build masonry structures because of being abundant, relatively easy to cut and shape and good performance in many applications.

Almost all of the historical buildings in Cyprus are made of these stones. Although these stones are low cost construction materials, they are not widely used in these days. This is due to lack of knowledge causing incorrect construction methods and highly skilled labour requirement.

For this study two quarries are selected and samples obtained were tested for some physical and mechanical properties.

The physical properties such as bulk density, water absorption, specific gravity and porosity were measured.

The mechanical properties such as compressive strength, flexural strength, direct tensile strength, splitting tensile strength, point load strength, fire resistance, abrasion resistance and freeze-thaw resistance were measured.

From the results obtained it can be said that in general **Meluşa** stone behaved better than **Karpaz** stone.

1. Material description

- Karpaz Stone (Bouri stone) from Yenierenköy
- Meluşa Stone from Kırıkkale village.

- Basically, these stones are limestone which vary dramatically from one type to another in hardness, density and porosity.

- The location of the sources of stones is shown in Fig. 1 on a geological map of Cyprus (*Dreghorn W., 1978*).

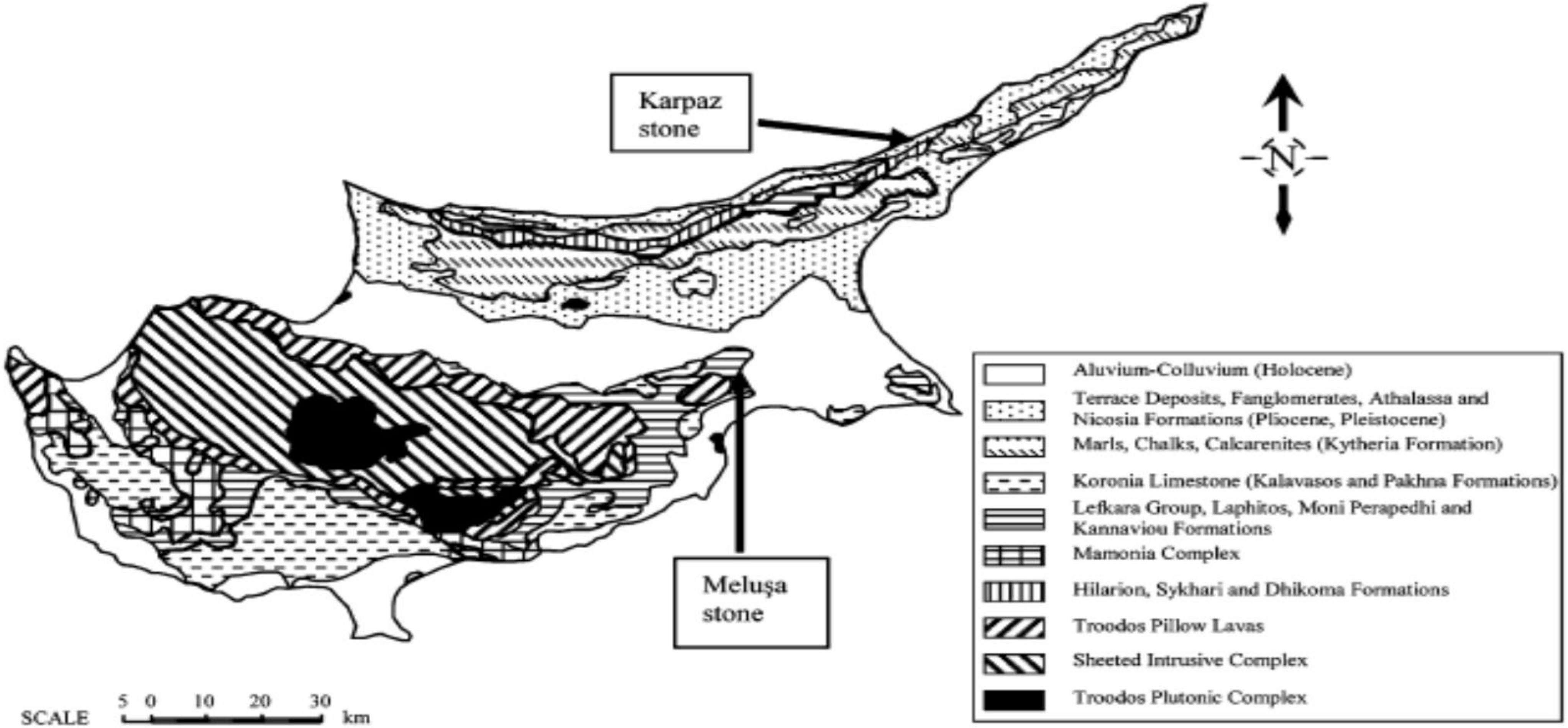

Fig.1 Geological map of Cyprus showing locations of Meluşa and Karpaz stones (*Dreghorn W., 1978*)

1.1 Meluşa stone

Meluşa Stone, which is shown in Fig. 2 (Bahalı M., 2002), is a rock which can be defined as micritic (mainly $CaCO_3$) limestone and it is utilized as an industrial raw material.

In past times, this natural resource rock had been known as 'Kiracıköy Stone' (Athineou Freestone). Nowadays, it is called 'Meluşa Stone', and it is distributed widely in the region between Kırıkkale village and Erdemli village (south-eastern part of Cyprus).

This rock corresponds to the lower section of Pahna formation (South Cyprus) and it is formed from thick medium layer of chalkstone (without chert (mainly SiO2)).

The source of these rocks which contain little clay mineral is determined as Globigerin fossils and their size can rise up to 300 microns.

The porosity between shell voids and particles is found to be between 20% and 25%.

The shell voids contain secondary calcite crystals derived from shell and the porosity between these calcite crystals are found to be between 20% and 25%.

Fig.2 Meluşa and Karpaz stones (*Bahalı M., 2002*)

1.2 Karpaz stone

Karpaz Stone, is a rock which can be defined as calcarenites which is a kind of limestone composed predominantly of clastic *sand-size grains* of calcite, or rarely aragonite, usually as fragments of shells or other skeletal structures.

These skeletal shells are fossils and sometimes size can be up to 30 mm. It is also reported that these natural stones are moved to the surface of sea water due to plate tectonics of the Island (*Tarımcıoğlu T., 1985*).

The particle size of calcarenite changes between 2 and 1/16 mm (medium size).

Calcarenite is a kind of detritic limestone and can also be defined as sandstone formed of carbonate minerals (*Gökçen L., 1982*).

They lithologically contain biocalcarenites, sandstone, sandy marls and conglomerates.

The Athalassa formation is a bioclastic limestone of about 3 m in thickness and covers much of the thrust structure in the Karpaz Peninsula where it forms extensive platforms (*Dreghorn W., 1978*).

2. Experiments

2.1. Physical properties (*Turkish Standards TS 699*)

- bulk density,
- water absorption,
- specific gravity,
- porosity

The results of these tests are as given in Table 1.

Table 1. Physical properties of Meluşa & Karpaz stones

Property	Meluşa stone	Karpaz stone
Bulk Density (g/cm^3)	1,73	1,51
Water absorption by mass (%)	11,93	18,17
Water absorption by volume (%)	20,50	28,20
Specific Gravity	2,69	2,68
Apparent Porosity (using water absorption, %)	20,50	28,20
Apparent Porosity (using bulk density, %)	50,60	27,50
Voids ratio	35,78	43,40

2.2. Mechanical properties

All the experiments were carried out under three different conditions (*Turkish Standard TS699 Natural building stones - Methods of inspection and laboratory testing*), namely:

Condition A: fully saturated,

Condition B: oven dried and cooled in airtight container,

Condition C: kept for 48 h at room temperature with 40–60% relative humidity.

2.2.1. Compressive strength

Cubic (70 mm) samples were cut with stone saw machine and tested for each condition (Conditions A–C) according to TS 699.

2.2.2. Flexural strength

Prizm samples were cut with stone saw machine for each condition (Conditions A–C) according to ASTM C 348.

2.2.3 Direct tensile strength

Cylinder samples (80x40 mm diameter) were cut with a stone saw machine and tested for each condition (Conditions A–C) according to *TS 699*

2.2.4 Splitting tensile strength test

For this experiment, 10 samples were cut (150 mm150 mm, D x L) by concrete drilling machine and tested for each condition (Conditions A–C) according to *TS 699*.

2.2.5. Point load strength test

This experiment determines the point load strength of stones according to *ASTM D 5731*

2.2.6. Fire resistance

This test was performed on samples for both flexural and compressive strength after burning them at 200, 300, 400, 500, 600, 800 and 1000°C.

Burning time was kept as 30 min after reaching the specified temperature for each series.

The sizes of test specimens were 70 mm cube for compressive strength test according to *TS 699* and 40x40x160 mm prism for flexural strength test according to *ASTM C 348*.

The burnt samples were put in airtight container to reach room temperature and tested.

2.2.7 Modified abrasion resistance test

Cubic specimens of sizes 50 mm are tested according to *ASTM C944*.

2.2.8. Los Angeles abrasion test

This test was done according to *TS 699* for both 100 and 500 revolutions.

At the end of the 100 and 500 revolutions, weight losses were calculated.

2.2.9. Accelerated freeze-thaw resistance

This test determines the accelerated freeze-thaw resistance of stones in terms of weight loss by using sodium sulphate solution according to *TS 699*.

3. Results and discussions

3.1. Physical properties

1. The bulk density of Meluşa stone is 14.57% higher than the bulk density of Karpaz stone.
2. The water absorption by mass of Karpaz stone is 52.3% higher than the water absorption by mass of Meluşa stone.
3. The water absorption by volume of Karpaz stone is 37.6% higher than the water absorption by mass of Meluşa stone.
4. The porosity of Karpaz stone is 21.2% higher than the porosity of Meluşa stone.

3.2. Compressive strength test (Fig.3)

1. The highest compressive strength is obtained to be 27.7 MPa for Condition B (oven dried), Meluşa Stones. It is reported elsewhere that compressive strength of limestones varies between 20 and 190 MPa for all directions depending on the silica content (*Hendry A.W., 2001*).
2. The lowest compressive strength is obtained to be 2.80 MPa for Condition A (fully saturated), Karpaz Stones. It is also reported that as saturation increases, strength decreases for limestones (*McNally G.H., 1988*).
3. The highest compressive strength is 9.89 times (90%) higher compared to lowest compressive strength.
4. Condition B (oven dried) has the highest compressive strength compared to all other conditions.
5. Test Condition A (fully saturated) gave the smallest compressive strength.

This might be due to water films which occur between particles, and sliding of particles over each other reduces the failure load compared to other conditions of test. Similar results were also obtained by Tarımcıoğlu (*Tarımcıoğlu T., 1985*). He determined that the loss in compressive strength with fully saturated samples is 90% compared to dry samples.

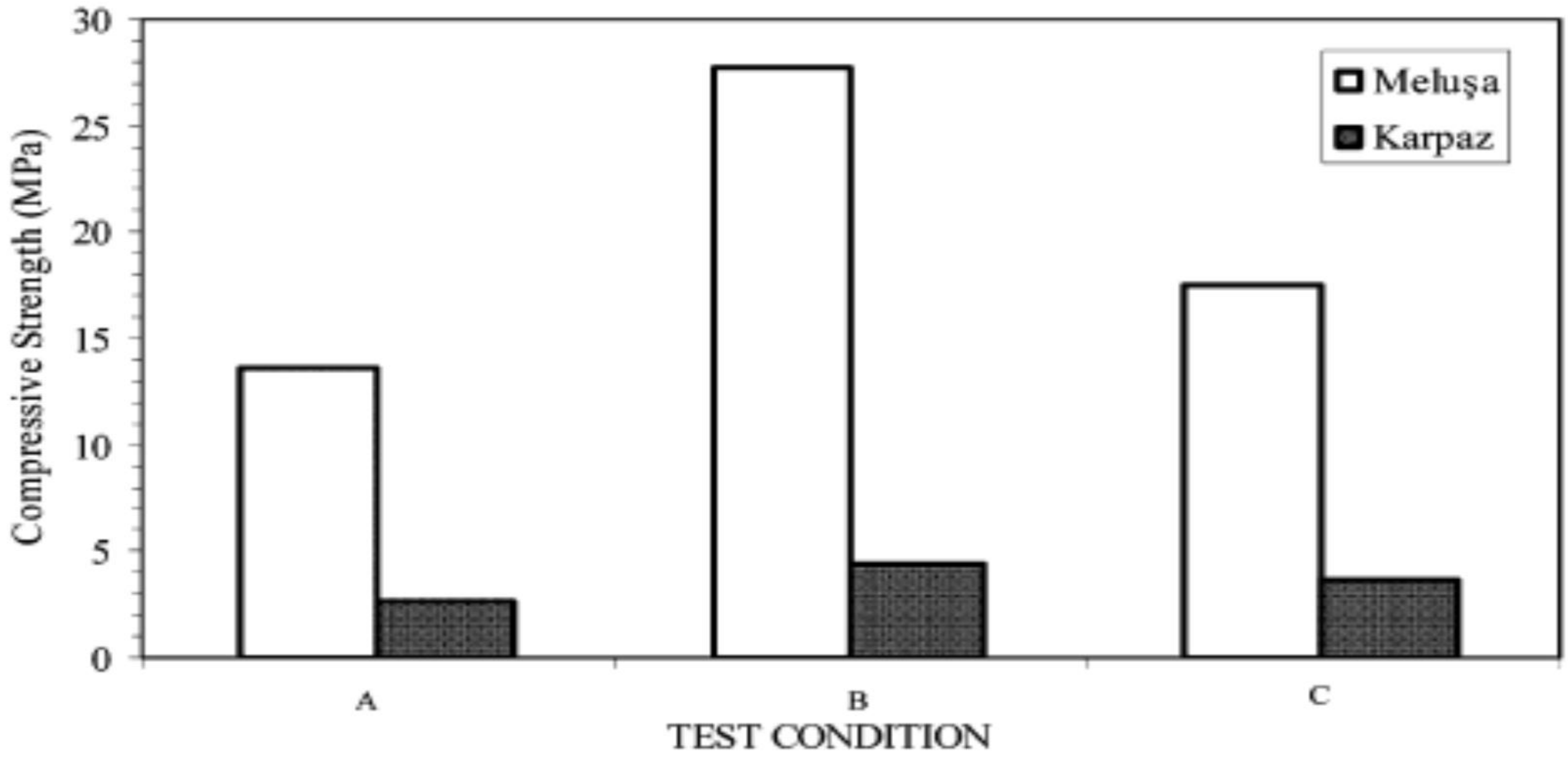

Fig. 3. Compressive strength results for three different test conditions.

3.3. Flexural strength test (Fig.4)

1. The highest flexural strength is obtained to be 6.23 MPa for Condition B (oven dried), Meluşa Stones.
2. The lowest flexural strength is obtained to be 1.43 MPa for Condition A (fully saturated), Karpaz Stones.
3. The highest flexural strength is 4.36 times (77%) higher compared to lowest flexural strength.

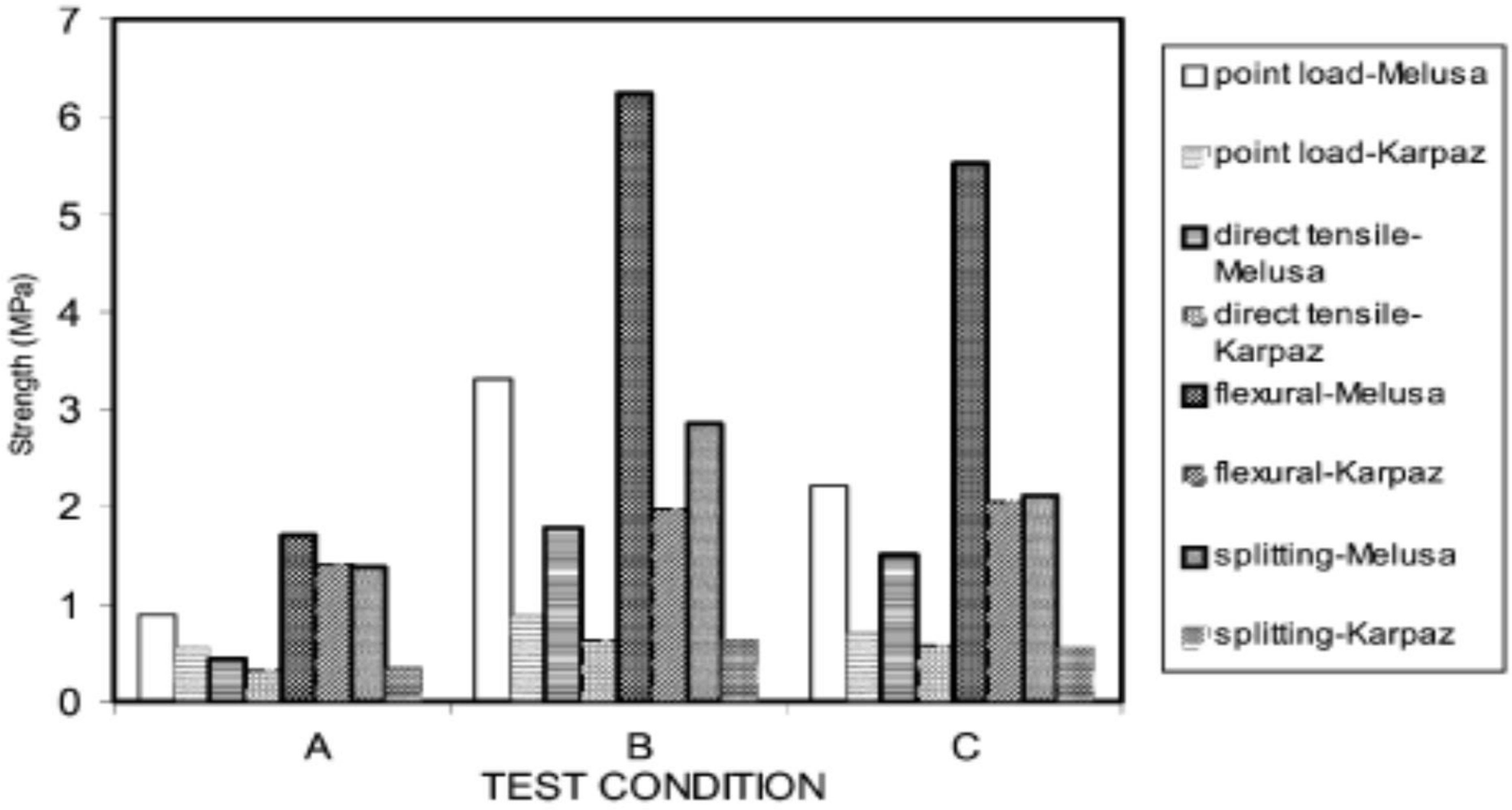

Fig. 4. Point load, direct tensile, flexural and splitting tensile strength results for three different test conditions.

3.4. Direct tensile strength test (Fig.4)

1. The highest direct tensile strength is obtained to be 1.78 MPa for Condition B (oven dried), Meluşa Stones.
2. The lowest direct tensile strength is obtained to be 0.34 MPa for Condition A (fully saturated), Karpaz Stones.
3. The highest direct tensile strength is 5.24 times (81%) higher compared to lowest tensile strength.
4. Condition B has the highest direct tensile strength compared to all other conditions.
5. Test Condition A (fully saturated) gave the smallest direct tensile strength. This might be due to water film which occur between particles, and sliding of particles over each other reduces the failure load compared to other conditions of test.

3.5. Splitting tensile strength test (Fig.4)

1. The highest splitting tensile strength is obtained to be 2.85 MPa for Condition B (oven dried), Meluşa Stones.
2. The lowest splitting tensile strength is obtained to be 0.35 MPa for Condition A (fully saturated), Karpaz Stones.
3. The highest splitting tensile strength is 8.14 times (87%) higher compared to lowest splitting tensile strength.
4. Condition B (oven dried) gave the highest splitting tensile strength compared to all other conditions.
5. Test Condition A (fully saturated) gave the smallest splitting tensile strength. This might be due to water film which occur between particles, and sliding of particles over each other reduces the failure load compared to other conditions of test.
6. The splitting tensile strength gave a tensile strength higher than that of the direct tensile test for all test conditions and both NBC stones. This strength ratio varies from unity to more than 2.5. Similar results were also reported by others (*Cardani G, Meda A., 1999*).

3.6. Point load strength test (Fig.4)

1. The highest point load strength value is obtained to be 3.30 MPa for Condition B (oven dried), Meluşa Stones.
2. The lowest point load strength value is obtained to be 0.57 MPa for Condition A (fully saturated), Karpaz Stones. This must be due to water film which occurs between particles and sliding of particles over each other reduces the failure load compared to other test conditions.
3. The highest point load strength value is 5.79 times (83%) higher compared to lowest point load strength.
4. Test Condition B (oven dried) gave the highest point load strength compared to all other conditions.

3.7. Fire resistance test (Fig.5)

3.7.1. Compressive strength test results after fire

1. The highest compressive strength is obtained to be 43.46 MPa for 200^{o}C (Meluşa Stones).
2. The highest compressive strength is 1.57 times higher compared to unburned compressive strength for Meluşa Stone.
3. The lowest compressive strength is obtained to be 1.68 MPa for 800^{o}C (Karpaz Stones).
4. The lowest compressive strength 2.65 times smaller compared to unburned compressive strength for Karpaz Stone.

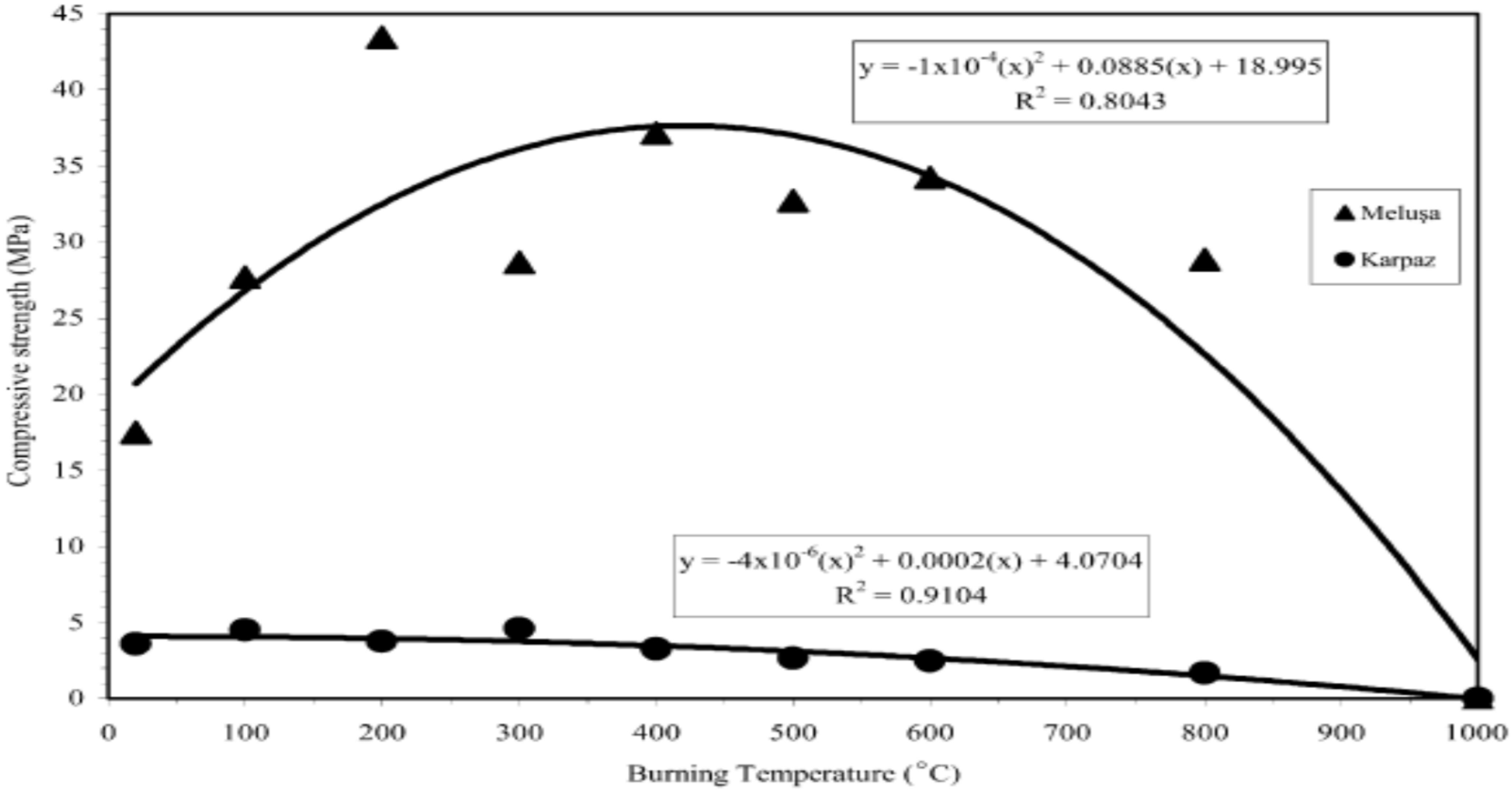

Fig. 5. Compressive strength results of Meluşa and Karpaz stones after burning at various temperatures.

5. The samples were observed to be dispersed at 1000 °C for both Meluşa Stone and Karpaz Stone.

6. The optimum burning temperature for Meluşa Stone is observed to be 200 °C.

7. The optimum burning temperature for Karpaz Stone is observed to be 300 °C.

8. For Karpaz Stone there is a tendency of decrease in compressive strength as burning temperature increases. Compressive strength of Meluşa Stone increases until 400 °C and starts to reduce after that temperature.

9. A regression analysis provided a polynomial relation between compressive strength and burning temperatures as shown in Fig. 5. It can be said that the correlation coefficients for both stones are high.

The change in behavior of stones at different temperatures could be explained as follows:

- In the temperature range of 15–100 °C; residual water is removed, between 150 °C and 250 °C; water bound by adsorption is removed, between 200 °C and 500 °C; organic material is destructed, between 450 °C and 650 °C; chemically bound water is removed, between 800 °C and 900 °C; carbonate is destructed and due to these the samples at 1000 °C are exploded.

3.7.2. Flexural strength test results after fire (Fig.6)

1. The highest flexural strength is obtained to be 7.98 MPa for 500 ^{o}C, Meluşa Stones.
2. The highest flexural strength is 1.28 times higher compared to unburned flexural strength value for Meluşa Stone.
3. The lowest flexural strength is obtained to be 0.61 MPa for 600 ^{o}C, Karpaz Stones.
4. The lowest flexural strength is 3.23 times smaller compared to unburned flexural strength value for Karpaz Stone.

5. The samples were observed to be dispersed at 1000 ^{o}C for both Meluşa Stone and Karpaz Stone.

6. The optimum burning temperature for Meluşa Stone is observed to be 400 ^{o}C.

7. The optimum temperature for Karpaz Stone is observed to be 20 ^{o}C (room temperature).

8. For Karpaz Stone there is a tendency of decrease in flexural strength as burning temperature increases. Flexural strength of Meluşa Stone increases until 400 C and starts to reduce after that temperature.

9. A regression analysis provided a polynomial relation between compressive strength and burning temperatures as shown in Fig. 6. It can be said that the correlation coefficients for both stones are high.

The change in behavior of stones at different temperatures could be explained as follows:

- In the temperature range of 15–100 ^{o}C; residual water is removed, between 150 and 250 ^{o}C; water bound by adsorption is removed, between 200 and 500 ^{o}C; organic material is destructed, between 450 and 650 ^{o}C; chemically bound water is removed, between 800 and 900 ^{o}C; carbonate is destructed and due to these the samples at 1000 ^{o}C are exploded.

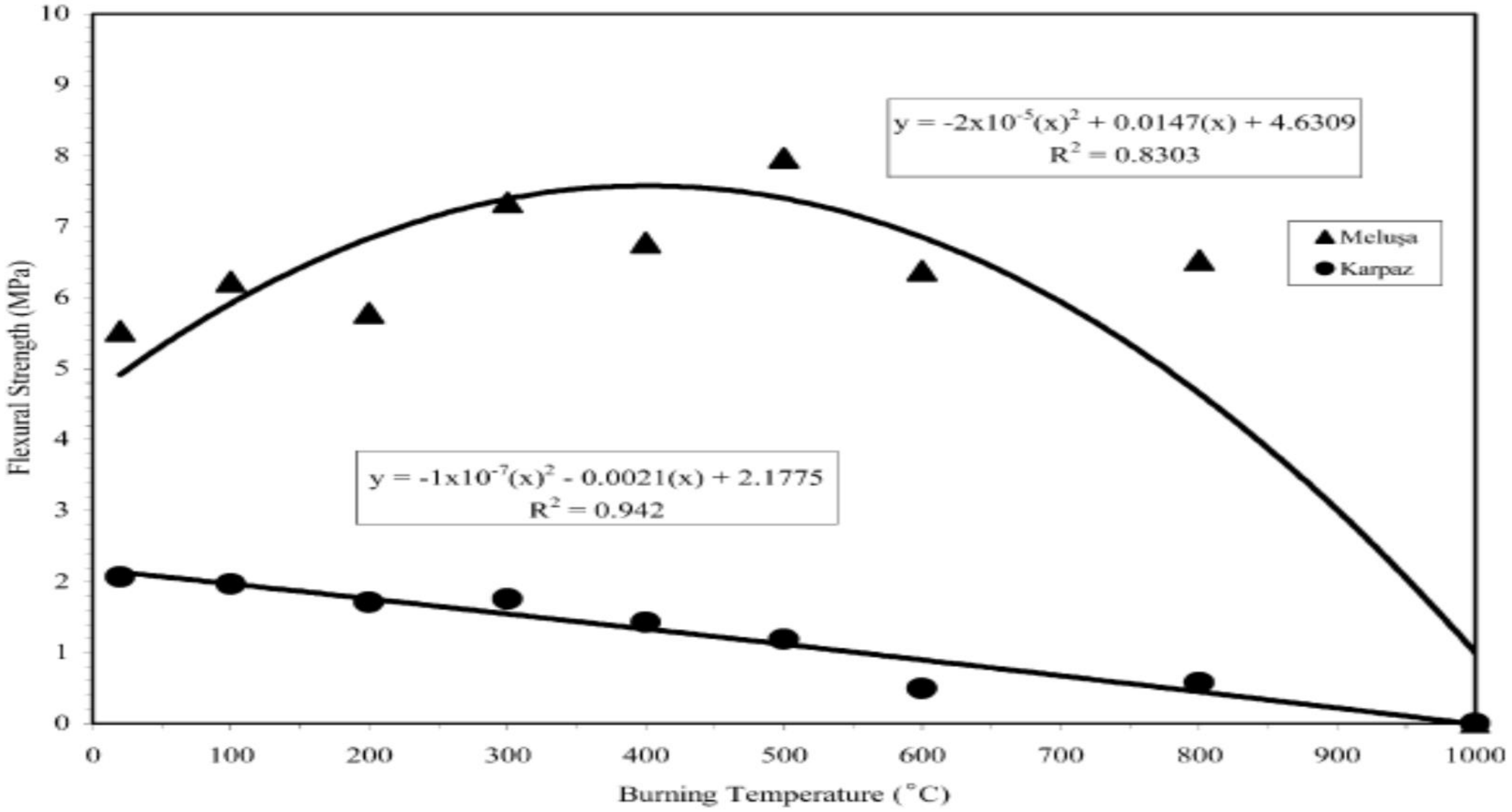

Fig. 6. Flexural strength results of Meluşa and Karpaz stones after burning at various temperatures.

3.8. Modified abrasion resistance test (Table 2)

1. Meluşa stone has less abrasion loss for all test Conditions of A–C. The lowest value is obtained to be 0.64% for test Condition A (fully saturated).
2. The highest abrasion loss is obtained to be 3% with Karpaz stones for test Condition C (40–60% relative humidity at room temperature).
3. The abrasion loss of Karpaz stone is 4.5 times higher compared to Meluşa stone. In other words, Meluşa stone is 4.5 times more resistant against abrasion compared to Karpaz stone.

Table 2. Some mechanical properties of Meluşa and Karpaz stones

Property	Meluşa stone			Karpaz stone		
Modified abrasion (% loss in wt)	0.64 (A[a])	1.40 (B[a])	1.66 (C[a])	2.40 (A[a])	2.86 (B[a])	3.00 (C[a])
Los Angeles abrasion (% loss in wt.)	10.10 (K100[b])	44.77 (K500[b])		42.30 (K100[b])	89.50 (K500[b])	
Accl. Freeze-thaw (% loss in wt.)	57.25			62.81		

a Test Conditions A-C
b Number of revolutions

3.9. Los Angeles abrasion test (Table 2)

1. Meluşa stone has higher abrasion resistance compared to Karpaz stone due to higher density formation.
2. The abrasion values (% loss in weight) for Meluşa stone are obtained to be 10.1% and 44.7% after 100 and 500 revolutions, respectively.
3. The abrasion values (% loss in weight) for Karpaz stone are obtained to be 42.3% and 89.5% after 100 and 500 revolutions, respectively.
4. For the case of 100 revolutions, the abrasion resistance of Meluşa stone is 4 times better than Karpaz stone.
5. For the case of 500 revolutions, the abrasion resistance of Meluşa stone is 2 times better than Karpaz stone.

3.10. Accelerated freeze-thaw resistance (Table 2)

1. The weight loss is 57.3% for Meluşa stone. This is 9.6% less compared to Karpaz stone. The degree of microporosity of a stone is a predominant factor in relation to its durability. Since, Karpaz stone has higher porosity compared to Meluşa stone, it is quite normal to have these results.
2. The weight loss is 62.8% for Karpaz stone.
3. In general, weight loss is quite high for both Meluşa and Karpaz stones. This can show us that the liability to sulphate attack is increased if the wall remains wet for a prolonged period and can be minimized by protection of stone from ingress of water.

4. Conclusions

4.1 Physical properties

- The bulk density of Meluşa stone is higher than the bulk density of Karpaz stone.
- The water absorption (by volume or by mass) of Karpaz stone is much higher than Meluşa stone.
- Porosity of Karpaz stone is bigger than the porosity of Meluşa stone.

4.2. Compressive strength

1. Meluşa stones for test Condition B (oven dried) gave 90% higher compressive strength compared to Karpaz stones for test Condition A.
2. The lowest compressive strength is obtained with Karpaz stone for Condition A (fully saturated), which is fully saturated.

4.3. Flexural strength

1. Meluşa stones for test Condition B (oven dried) gave 77% higher flexural strength compared to Karpaz stones for test Condition A (fully saturated).
2. The lowest flexural strength is obtained with Karpaz stone for Condition A (fully saturated).

4.4. Direct tensile strength

1. Meluşa stones for test Condition B (oven dried) gave 81% higher direct tensile strength compared to Karpaz stones for test Condition A (fully saturated).
2. The lowest direct tensile strength is obtained with Karpaz stone for Condition A (fully saturated).

4.5. Splitting tensile strength

1. Meluşa stones for test Condition B (oven dried) gave 87% higher splitting tensile strength compared to Karpaz stones for test Condition A (fully saturated).

2. The lowest splitting tensile strength is obtained with Karpaz stone for Condition A (fully saturated).

4.6. Point load strength

1. Meluşa stones for test Condition B (oven dried) gave 83% higher point load strength compared to Karpaz stones for test Condition A (fully saturated).

2. The lowest point load strength value is obtained with Karpaz Stones for Condition A (fully saturated).

4.7. Compressive strength after fire test

1. The highest compressive strength is obtained with Meluşa stone at 200 ^{o}C.
2. The lowest compressive strength is obtained with Karpaz stone at 800 ^{o}C.
3. It is observed that both Meluşa and Karpaz stones are dispersed at 1000 ^{o}C.
4. A regression analysis provided a polynomial relation between compressive strength and burning temperatures.

4.8. Flexural strength after fire test

1. The highest flexural strength is obtained with Meluşa stone at 500 ^{o}C.
2. The lowest flexural strength is obtained with Karpaz stone at 600 ^{o}C.
3. It is observed that both Meluşa and Karpaz stones are dispersed at 1000 ^{o}C.
4. A regression analysis provided a polynomial relation between flexural strength and burning temperatures.

4.9. Modified abrasion resistance test

1. Meluşa stone has better abrasion resistance than Karpaz stone.
2. The abrasion resistance of Meluşa stone is 4.5 times better than Karpaz stone.

4.10. Los Angeles abrasion test

1. Meluşa stone has higher abrasion resistance compared to Karpaz stone due to higher density formation.
2. Meluşa stone has 4 times higher abrasion resistance for the case of 100 revolutions compared to Karpaz stone.
3. Meluşa stone has 2 times higher abrasion resistance for the case of 500 revolutions compared to Karpaz stone.

4.11. Accelerated freeze-thaw resistance

1. Meluşa stone has higher freeze-thaw resistance compared to Karpaz stone.
2. The freeze-thaw resistance of Meluşa stone is 9.6% higher compared to Karpaz stone.
3. In order to increase the freeze-thaw resistance of buildings made of NBC stones, a protection is needed to reduce the ingress of water.

Thank you