Mugla Journal of Science and Technology

THE EFFECT OF SAMPLE SIZE ON THE FLEXURAL STRENGTH OF SEDİMENTARY CARBONATE ROCKS UNDER CONCENTRATED LOAD

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Received: 14.12.2020, Accepted: 29.01.2021 Research Article
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DOI: 10.22531/muglajsci.840663

Abstract

Flexural strength is an important mechanical property used in the selection of the application area of natural building stones. The flexural strength of natural stones in our country is determined according to the test standards prepared by the European Union. According to TS EN 12372, the recommended test sample dimensions for the determination of the flexural strength of natural stones are 50×50×300 mm. However, generally, 20-30 mm thick plates are used in flooring, cladding, and exterior applications in buildings. In practice, 50 mm thick plates are rarely used, as well as preparing 50 mm thick test samples is a laborious and time-consuming process. In this study, it has been investigated how much the sample size affects the flexural strength of sedimentary carbonate rocks when using test samples prepared in two different sizes. It has been observed that the flexural strength values obtained from the test samples prepared in different sizes of the same rock are very close to each other. Besides, the stress distributions formed on the rock sample were analyzed with ANSYS Workbench 2020 R1. It has been determined that the stress distributions in the samples prepared in different sizes, exposed to the same load, occur in the same regions, and concentrate.
Keywords: Natural Stone, Flexural Strength, Size Effect, Standardization

SEDİMANTER KARBONATLI KAYAÇLARDA ÖRNEK BOYUTUNUN YOĞUN YÜK ALTINDA BÜKÜLME DAYANIMINA ETKİSİ

Özet

Eğilme dayanımı, doğal yapı taşlarının uygulama alanı seçiminde kullanılan önemli bir mekanik özelliktir. Ülkemizde doğal taşların eğilme dayanımları Avrupa Birliği'ne uygun olarak hazırlanan deney standartlarına göre belirlenmektedir. TS EN 12372 standardına göre doğal taşların eğilme dayanımı tayini için önerilen deney numunesi ölçüleri 50×50×300 mm'dir. Ancak binalarda yer ve duvar döşemesi uygulamalarında genellikle 20-30 mm kalınlığında plakalar kullanılmaktadır. Pratikte 50 mm kalınlığındaki plakaların çok nadir kullanılmasının yanında 50 mm kalınlığında test numunesi hazırlamak da zahmetli ve zaman alıcı bir işlemdir. Bu çalışmada, iki farklı boyutta hazırlanan deney numunelerinin kullanılması durumunda örnek boyutunun karbonatlı kayaçların eğilme dayanımlarını ne kadar etkilediği araştırılmıştır. Aynı kayaya ait farklı boyutlarda hazırlanan deney numunelerinden elde edilen eğilme dayanımı değerlerinin birbirine çok yakın olduğu görülmüştür. Ayrıca kaya numunesi üzerinde oluşan gerilme dağılımları ANSYS Workbench 2020 R1 ile analiz edilmiştir. Aynı yüke maruz kalan farklı boyutlarda hazırlanmış numunelerde gerilme dağılımlarının aynı bölgelerde meydana geldiği, yoğunlaştığı tespit edilmiştir.
Anahtar Kelimeler: Doğal Taş, Eğilme Dayanımı, Boyut Etkisi, Standartlaşma

Cite

Akbay, D., Şengün, N., Ekincioğlu, E., Altındağ, R., (2021). "The Effect of Sample Size on The Flexural Strength of Sedimentary Carbonate Rocks Under Concentrated Load", Mugla Journal of Science and Technology, 7(1), 36-43.

1. Introduction

Natural stones have been used in many different areas, especially in architectural structures as building stones, from ancient times to the present. Its aesthetic appearances, features such as being resistant to environmental factors have always brought natural stones to the fore. For example, natural stones with suitable water absorption features in Turkish baths, natural stones with low resistance loss under atmospheric conditions in exterior claddings, natural stones with high thermal resistance properties in bakeries, etc. are preferred. Sometimes they are preferred in interior wall claddings because of their aesthetic appearance regardless of their other properties. By determining the physical and mechanical properties of natural stones, the most suitable usage areas can be determined, and thus their service life increases. These properties, which were determined by methods based on experience and observation in ancient times, are determined by standardized test methods today. One of the most important mechanical properties to be determined for natural stones used as flooring is flexural strength. In flooring applications, determining flexural strength and failure mechanisms of natural stones are very vital for their service life.

The CE mark, which is mandatory for products such as natural stones sold to European Union countries, certifies that these products have sufficient properties. Determination of flexural strength under concentrated load test is one of the tests required for the CE marking of natural stone products to assess their mechanical strength [1]. According to TS EN 12372 [2], the suggested dimensions for stones with a size of the grain lower than 25 mm are 50×50×300 mm or other dimensions can be used if it fulfills the following specified requirement:

- the thickness (h): 25 mm < h < 100 mm (should be greater than twice the size of the largest grain in the stone),
- the width (b): 50 mm ≤ b ≤ (3h) (it shouldn't be less than the thickness),
- total length (L): 6 h,
- distance between the supporting rollers (l) = 5 h.

However, the producers and importers of the slabs are often unable to test their products in compliance with the standardized test method, because a sample thickness of 50 mm is required for the EN 12372 standard. Because products with a thickness of varying between 20 - 30 mm are used in flooring applications in buildings and the test samples are usually taken from the production line, the existing thickness is constant, the width and the length of the sample are dimensioned according to the related standard and sent to who is in charge of the application of the CE marking. Therefore, samples with a thickness varying between 25-30 mm are often used in the tests.

Many studies have been carried out on the flexural strength of materials [3-8]. The effects of the sample size on the flexural strength are generally studied on concrete samples by researchers [9,10,19-21,11-18]. A few researchers have investigated the size effect on the flexural strength of rocks [1,15,22]. Flexural strength is also used to predict the tensile strength of the rocks, concrete, glass, wood, etc. Numerous researchers conducted studies in which they supported laboratory studies with numerical analysis [4,10,23,24].

This study aims to determine whether the sample size changes the flexural strength in sedimentary carbonate rocks.

2. Material and method

Sedimentary carbonate rock samples were obtained from various natural stone processing plants located in different regions of Turkey. The rocks used in the study were selected to create a range from low strength value to high strength value in order to represent rocks with different strength values. 10 different sedimentary carbonate rock samples were investigated in this study (Table 1). All rocks contain over 50% carbonate minerals. A detailed mineralogical and petrographic analysis has not been performed on the studied rocks.

Table 1. Sedimentary carbonate rocks used in the study.

Sample Code	Lithological Name	Origin	Region
LS-1	Travertine	Sedimentary	Aksaray
LS-2	Travertine	Sedimentary	Denizli
LS-3	Travertine	Sedimentary	Denizli
LS-4	Limestone	Sedimentary	Isparta
LS-5	Limestone	Sedimentary	Isparta
LS-6	Limestone	Sedimentary	Sivas
LS-7	Limestone	Sedimentary	Bursa
LS-8	Limestone	Sedimentary	Burdur
LS-9	Limestone	Sedimentary	Bursa
LS-10	Dolomite	Sedimentary	Isparta

Tests to determine physical and mechanical properties were carried out by the related standards and suggested methods. The total porosity tests were performed as specified in TS EN 1936 [25], ultrasonic wave velocity tests were performed as specified in TS EN 14579 [26], the uniaxial compressive strength, and Brazilian tensile strength tests were performed as specified in ISRM [27]. The test results were presented in Table 2. The tests were performed in the Natural Stone Technology and Excavation Mechanics Laboratory of Mining Engineering Department at Süleyman Demirel University.

2.1. The Flexural Strength Tests

Flexural strength is a measure of the tensile strength of the outer fiber of a material. In the flexural strength test, a vertical load is applied in the vertical direction from the middle of the sample standing on two supports. In this study, flexural strength tests were carried out on samples of dimensions 25×50×150 mm and 50×50×300 mm by TS EN 12372 [2] (Fig. 1 and Fig. 2). 10 samples were tested for each dimension and rock type. The flexural strength (MPa) is a function of the sample thickness (h), the width (b), and the distance between the supporting rollers (l) all in mm, as in the following Equation (1):

$$\sigma_{fs} = \frac{3Fl}{2bh^2} \qquad (1)$$

where F is the failure load (N). The arithmetic means were calculated for each dimension and rock type and given in Table 3.

3.1. Experimental Study

The results obtained from this study, which examines the flexural strength of samples of different sizes, are given in this section. The flexural strength values obtained from different size samples are given in Table 2. When Table 2 is examined, it is seen that the flexural strength values obtained from the samples of 25×50×150 mm dimension vary between 6.81-22.95 MPa and that the flexural strength values obtained from the samples of 50×50×300 mm dimension vary between 5.15-19.43 MPa. It is observed that the flexural strength values obtained from different-sized samples belonging to the same rock are very close to each other (Fig. 3). It has appeared that the flexural strength values obtained from the samples of 25×50×150 mm dimension are higher than the flexural strength values obtained from the samples of 50×50×300 mm dimension. It was determined that the maximum difference between the flexural strength values obtained from the samples of 25×50×150 mm and the flexural strength values obtained from the samples with dimensions of 50×50×300 mm was in the sample coded LS-4 with 3.53 MPa. It was detected that the minimum difference between the flexural strength values obtained from the samples of 25×50×150 mm and the flexural strength values obtained from the samples with dimensions of 50×50×300 mm was in the sample coded LS-8 with 0.01 MPa. When the percentages of change in flexural strength values are examined, it was determined that the biggest change was in the sample coded LS-10 with 24.5%, and the smallest change was in the sample coded LS-8 with 0.1%.

To examine the relationship between flexural strength values obtained from 25×50×150 mm size samples and flexural strength values obtained from 50×50×300 mm size samples, the distribution graph of flexural strength values obtained from 25×50×150 mm size samples corresponding to flexural strength values obtained from 50×50×300 mm size samples were plotted (Fig. 4). It was determined that there is a linear relationship with a high correlation coefficient (r = 0.97) between them.

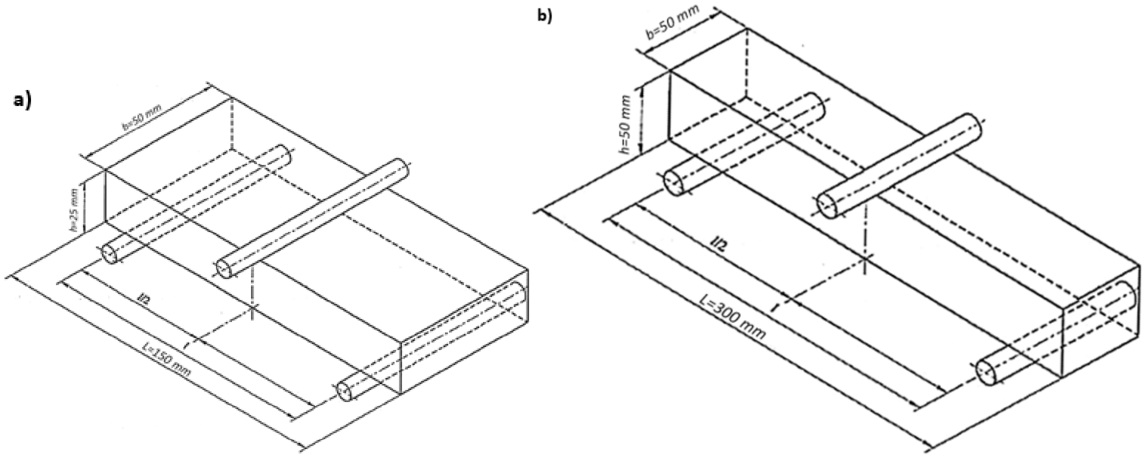

Figure 1. Technical drawings of samples with different dimensions a) TS EN 12372 (25×50×150mm) b) TS EN 12372 (50×50×300mm).

Figure 2. Flexural strength tests with different sized samples a) TS EN 12372 (25×50×150mm) b) TS EN 12372 (50×50×300mm).

Table 2. The flexural strength (σ_{fs}) test results (MPa) with different sized samples.

Sample Code	25×50×150 mm		50×50×300 mm	
	x̄	sd	x̄	sd
LS-1	11.18	1.39	9.97	1.87
LS-2	11.12	1.29	10.56	1.67
LS-3	11.92	1.34	11.18	1.81
LS-4	22.95	2.04	19.43	1.47
LS-5	10.18	2.39	9.84	0.64
LS-6	12.84	1.03	12.36	0.69
LS-7	12.63	1.92	10.34	1.95
LS-8	18.86	2.25	18.85	3.67
LS-9	9.58	2.85	9.20	1.07
LS-10	6.81	1.60	5.15	1.40

x̄: average; sd: standard deviation

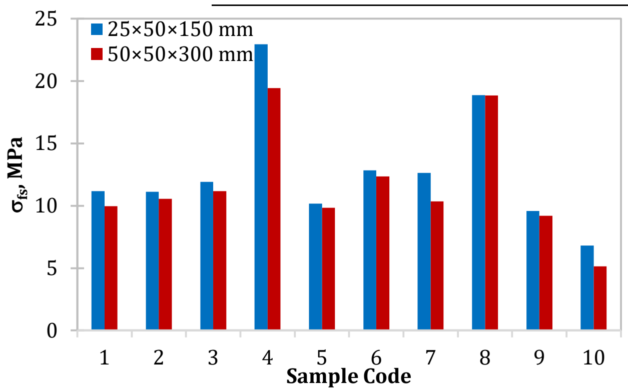

Figure 3. Comparison of flexural strength values obtained from the samples 25×50×150 mm vs flexural strength values obtained from the samples 50×50×300 mm.

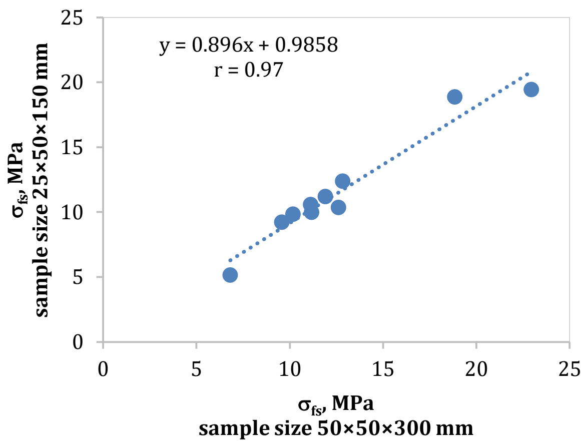

Figure 4. Flexural strength values obtained from the samples 25×50×150 mm vs flexural strength values obtained from the samples 50×50×300 mm.

Physical and mechanical properties determined by laboratory experiments are summarized in Table 3. The tests were carried out by TS EN standards and ISRM suggested methods.

The relationships between the determined physical and mechanical properties of the rocks and their flexural strength values were examined by simple regression analysis method. However, significant relationships could not be determined due to the developed fractured crack structures of sedimentary carbonate rocks. The relationships between ultrasonic wave velocity values and flexural strength values of tested rocks for both sizes of samples are given in Fig. 5. Weak linear correlations were determined between ultrasonic wave velocity values and flexural strength values of tested rocks for both sizes of samples with a correlation coefficient of r = 0.60 and r = 0.66 respectively and it is also seen that the data points with no clear trend (Fig. 5).

3.2. Numerical Study

In the flexural strength tests applied to geometrically similar prismatic samples of two different sizes, the stress distributions formed on the rock sample were analyzed with ANSYS Workbench 2020 R1. For Young's modulus and poisson's ratio values required for static stress analysis, the default values defined for the limestone embedded in the software were used. In the analysis, both different sized samples were subjected to the load of the amount required to achieve maximum stress of 5 MPa on cross-section, which was approximately the minimum flexural strength value of the tested rocks. While performing static stress analysis, Von mises stresses are given good results in ductile materials, whereas principal stresses should be considered for brittle materials such as carbonate rocks.

The maximum principal stress distributions in the front and lower faces obtained at the end of the analyses for each standard test sample are given in Fig. 6 and Fig. 7. The positive values show tensile stresses and the negative ones show compressive stresses. When Fig. 6 and Fig. 7 are examined, the maximum compressive stress occurs at point A, while the maximum tensile stress occurs at point B as expected in both sized samples. Since the tensile strength of rocks is lower than their compressive strength, the moment of failure is the moment when the tensile strength of point B is exceeded. This the main reason why the flexural strength is a measure of the tensile strength of the outer fiber of a material. The stress distributions and boundaries were similar on each sized rock samples.

4. Conclusion

The flexural strength is a key parameter in describing the characterization of natural stones. The effect of sample size on the flexural strength of rocks has not been examined and well defined in previous studies. This study aims to investigate and present the effect of sample size on the flexural strength of sedimentary carbonate rocks. Flexural strength tests were carried out using samples prepared in two different sizes from 10 different sedimentary carbonate rock samples and the results obtained were analyzed both statistically and numerically.

Table 3. The Physical and mechanical properties of the samples.

Sample Code	d_0 g/cm³	UW g/cm³	WAW %	OP %	TP %	*Vp* m/s	σ_c MPa	σ_t MPa
LS-1	2.715	2.485	1.841	4.519	8.48	5134	59.0	3.4
LS-2	2.710	2.342	3.032	7.051	13.59	5359	39.0	3.8
LS-3	2.699	2.357	2.204	5.186	12.66	5333	41.3	4.4
LS-4	2.773	2.746	0.132	0.364	0.97	6376	160.5	6.0
LS-5	2.737	2.706	0.054	0.145	1.13	6281	138.4	6.7
LS-6	2.733	2.702	0.038	0.103	1.14	6397	138.4	8.2
LS-7	2.735	2.695	0.096	0.260	1.45	6306	146.9	5.7
LS-8	2.775	2.740	0.249	0.683	1.26	6429	103.8	5.3
LS-9	2.732	2.701	0.145	0.391	1.11	6103	113.6	7.4
LS-10	2.871	2.719	1.290	3.480	5.29	3954	118.7	5.7

d_0: density; UW: unit weight; WAW: water absorption percentage by weight; AP: open porosity; TP: total porosity; *Vp*: ultrasonic wave velocity; σ_c: uniaxial compressive strength; σ_t: Brazilian tensile strength

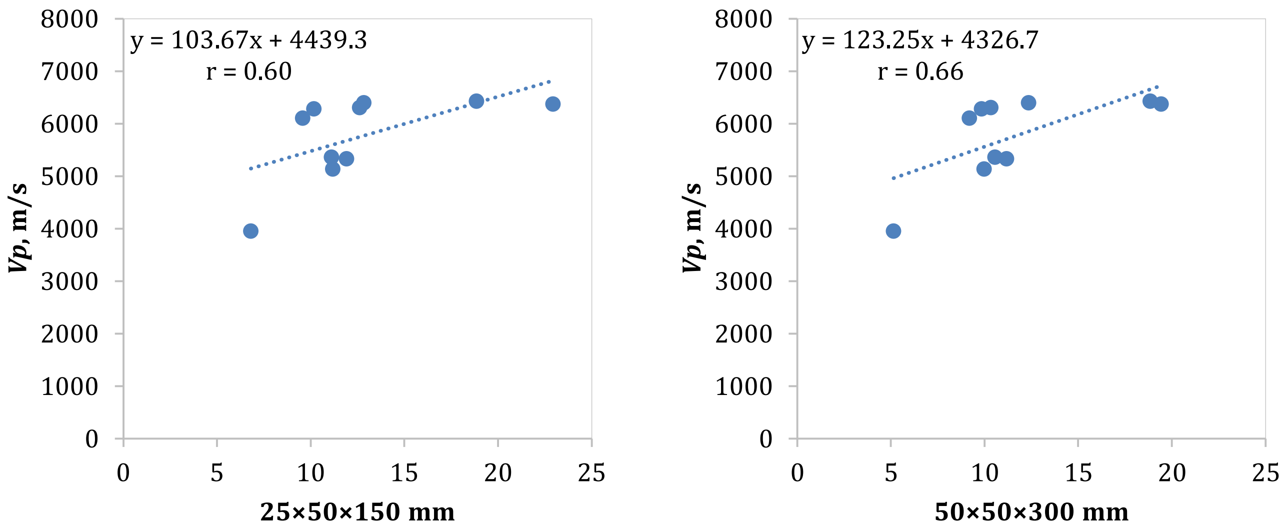

Figure 5. The relationships between ultrasonic wave velocity values and flexural strength values of tested rocks.

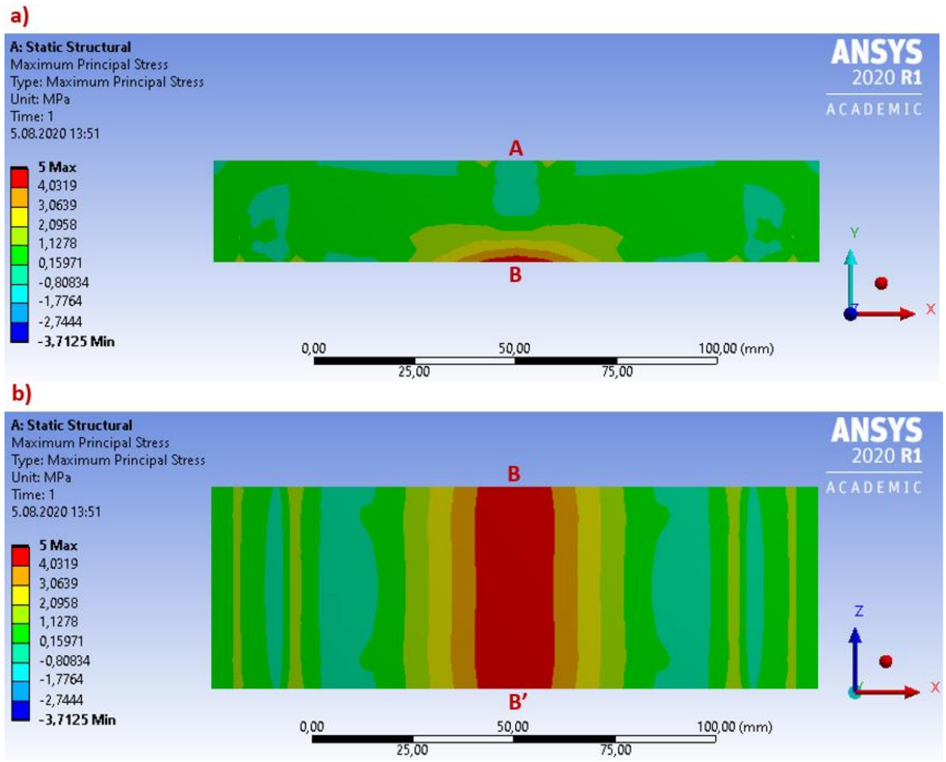

Figure 6. Stress distributions under concentrated load 25×50×150 mm sized sample a) A-B section: front face, b) B-B' section: lower face.

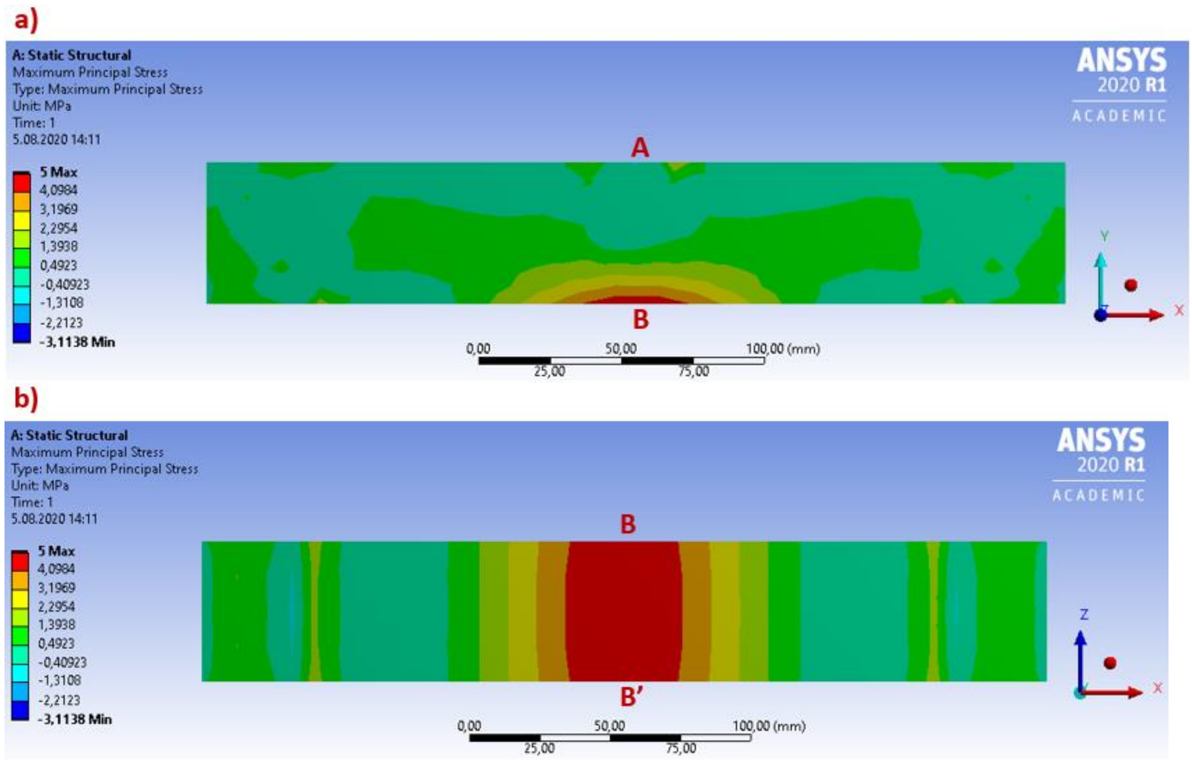

Figure 7. Stress distributions under concentrated load 50×50×300 mm sized sample a) A-B section: front face, b) B-B' section: lower face.

It is seen that the values obtained using two different sample sizes were close to each other. The differences between the values obtained from different sizes of the sample were change in 0.01-3.53 MPa and 0.1% and 24.5% in percentage. It has appeared that the flexural strength values obtained from the samples of 25×50×150 mm dimension were higher than the flexural strength values obtained from the samples of 50×50×300 mm dimension. It is thought that the reason for this is that as the size of the sample increases, the possibility of having cracks, fractures and defects in it increases. Small-sized samples may be preferred to avoid these errors. In this case, small samples should be preferred for determining the flexural strength of the sedimentary carbonate rocks due to difficulties in preparing large test samples.

In the literature, it is seen that the flexural strength values obtained from small size samples are higher than the flexural strength values obtained from relatively large size samples for concrete samples, similar to the results obtained in this study [9,16–19].

According to TS EN 12372 [2], the suggested dimensions for stones with a size of the grain lower than 25 mm are 50×50×300 mm or other dimensions ranging from 25×50×150 mm to 100-300-600 mm can be used if it fulfills some specified requirements. However, most of the equipment available in existing laboratories and their display gauge scales are not sufficient to experiment on large-sized samples. Therefore, small-sized samples should be preferred for ease of measurement process.

It is not easy to prepare large size samples due to the developed broken crack structure, especially in sedimentary carbonate rocks. Due to the fractures and cracks, it may not be possible to prepare a sufficient number of large samples from a rock block brought from the field to the laboratory. In such cases, it will be easier to prepare more small-sized samples.

The flexural strength is a function of the sample thickness, the width, and the distance between the supporting rollers. As a result of the finite element analysis, stress distributions in the different sized samples exposed to the same load occur in the same regions. This study underlines that the sample size has no significant effect on flexural strength.

It was observed from the numerical analysis, the stress distributions formed on the sample under load were similar to those in the literature [4,22]. The maximum compressive stress occurs at the point where the load is applied, while the maximum tensile stress occurs on the bottom surface of the point where the load is applied.

Studies on rocks of different geological origins are important for obtaining new findings. It will be possible to obtain more common findings by performing this study on samples of different sizes and also on samples with anisotropic properties.

Although there are no limit values for flexural strength in Turkish and European standards, it is known that there are limit values in the standards of many countries in the world (USA, Israel, and many Middle Eastern countries). To avoid the confusion caused by the difference in the values to be obtained by using samples of different sizes, a conversion coefficient can be suggested for the values that will correspond in these countries when using samples of different sizes in future studies.

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