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Araştırma Makalesi / Research Article

Effect of Aggregates with Different Physical Properties on Concrete Strength for Different *Water to Cement Ratio* and Different Cement Content

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Abstract

Aggregates have a large volume in concrete, therefore they directly affect the properties of concrete. Aggregate, which is expected to give desirable strength in concrete, should be examined especially in terms of its physical properties and grain size. In this respect, aggregate to be used in concrete must not be easily broken, non-abrasion quickly, and must be strong and hard structure. While low strength is obtained in concrete produced with porous lightweight aggregates, high strength is observed in concrete produced with high-density aggregates. In addition, aggregates have an effect on concrete properties such as concrete workability and permeability. One of the aggregates commonly used in concrete production is limestone aggregate. In this study, the effects of limestone aggregates with different properties on compressive strength and splitting tensile strength were investigated experimentally. In this context, cubic specimens of 150×150×150 mm dimensions were prepared for different water/cement ratios, different cement contents, and different aggregate properties. With these specimens, after the cure period of 28 days, the relevant strength tests were performed. The strength values of these concrete specimens were compared and the results were discussed. As a result; it has been determined that the concrete strengths obtained by considering the relevant standards are compatible with the literature. Thus, in this study, it has been determined that aggregates tested for use in concrete have positive effects on concrete strength.

Keywords

Compressive strength;
Splitting tensile
strength; Concrete;
Aggregate; Limestone
Aggregate

Farklı Fiziksel Özelliklere Sahip Agregaların Farklı *w/c* Oranı ve Farklı Çimento Dozajı için Betonun Dayanımına Etkisi

Öz

Betonda hacim olarak büyük yer kapladığından dolayı agregalar; betonun özelliklerini doğrudan etkilemektedirler. Betonda iyi dayanım özelliği vermesi beklenen agrega, özellikle fiziksel özellikleri ve granulometrisi bakımından incelenmelidir. Bu bakımdan, betonda kullanılacak agreganın kolayca kırılmayan, çabuk aşınmayan, sağlam ve sert yapıda olması gerekmektedir. Gözenekli hafif agregalar ile üretilen betonlarda düşük dayanım elde edilirken yoğunluğu yüksek agregalar ile üretilen betonlarda yüksek dayanım gözlenmektedir. Ayrıca, agrega özelliklerinin; betonun işlenebilirliği, geçirgenliği gibi beton özellikleri üzerinde de etkisi vardır. Beton üretiminde yaygın olarak kullanılan agregalardan biri kalker agregasıdır. Bu çalışmada farklı özelliklere sahip kalker agregalarının basınç dayanımına ve yarmada çekme dayanımına etkileri deneysel olarak araştırılmıştır. Bu kapsamda farklı su/çimento oranı, farklı çimento dozajı ve farklı agrega tipleri için 150*150*150 mm boyutlarında küp numuneler hazırlanmıştır. Bu numuneler üzerinde, 28 günlük kür süresi uygulandıktan sonra ilgili dayanım testleri gerçekleştirilmiştir. Bu agregalar ile üretilen beton numunelerin dayanımları karşılaştırılmış ve sonuçlar tartışılmıştır. Sonuç olarak; ilgili standartlar göz önünde bulundurularak elde edilen beton dayanımlarının literatürle uyumlu olduğu belirlenmiştir. Böylece bu çalışmada betonda kullanımı test edilen söz konusu agregaların beton dayanımına olumlu etkileri olduğu belirlenmiştir.

Anahtar kelimeler

Basınç dayanımı;
Yarmada çekme
dayanımı; Beton;
Agrega; Kireçtaşı
agregası

1. Introduction

Concrete is a building material that water, cement, aggregate, and additives are formed by mixing homogeneous in a certain ratio, initially fluid and hardening over time. The volume of concrete is approximately 70% aggregate, 10% cement, and 20% water. Concrete is preferred more than other building materials because of its appropriate shape, economic, durable, less energy consumption in production, it can be produced anywhere and its aesthetic properties. The use of the amount of the annual per capita use of concrete in the world and Turkey is estimated that close to 1 m³ (Akdag and Mutlu 2013, Tanguler 2014).

As Turkey is located in the earthquake zone, it is of great importance that the concrete structures are of high quality. In order for the hardened concrete to be of good quality, the mixes of the concrete must first be suitable. In order to obtain a concrete with high quality and performance, the concrete design alone is not sufficient and all stages from production to control must be performed with precision. In researches on concrete, concrete quality is generally evaluated with compressive strength. It has been observed that concrete compressive strength and hardened concrete properties change in a parallel direction (Felekoğlu and Türkel 2005, Şanal 2018, Tunç 2019b).

Aggregates, which constitute about 70% of concrete, are preferred as a filling material in the concrete content because of the very low cost compared to cement. Aggregates used in the concrete increase the resistance of the concrete against environment and help to provide the desired strength from the concrete (Erdoğan 1995, Tunç and Alyamaç 2019).

In literature, Abrams' law has been examined and it has been found that cement mortars ranging from very low strength to very high strength can be obtained (Rao 2001). Also, the effect of water to cement ratio and cement to fine aggregate ratio on compressive strength in Singh et al. (2015). Thus,

the applicability of Abrams' law has been proven. The optimum water to cement ratio and cement to the fine aggregate ratio were determined. There are also studies conducted in the literature to determine whether aggregates play an important role in concrete strength (Lo et al. 2007; Beushausen and Dittmer, 2015). Thus, it is possible to produce different strength concrete such as lightweight concrete and high strength concrete by using aggregates with different properties.

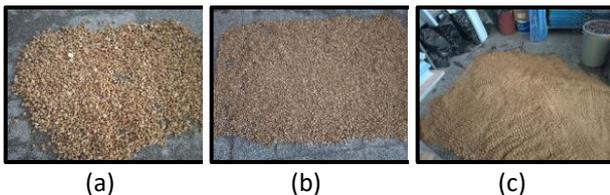
It was determined in a previous study that using limestone as aggregate for normal strength concrete increases the strength by 12% compared to the reference concrete (Meddah et al., 2010). Cement and chemical additives are also important in determining concrete strength properties (Tunc, 2019a).

It is important to note that the porosity of concrete increases with the increase of water to cement ratio. Because when the water to cement ratio changed from 0.45 to 0.60, it was determined that porosity increased to 150% and the strength decreased by 75.6% (Kim et al., 2014).

The aim of the present study is to determine the hardened properties of concrete including limestone aggregates with different properties. For this purpose; concrete mixes were prepared for cement content 300-400 kg/m³ and water to cement ratios of 0.50-0.60. A series of 150×150×150 mm cubic specimens were poured for the measurement of compressive strength and splitting tensile strength values. Then, these tests were conducted on these specimens. In addition, the fresh concrete properties of the obtained concrete mixtures were determined. All related results were compared and the effects of different types of limestone aggregates on concrete strength were investigated. As a result of this experimental study, it is recommended to use the limestone aggregates safely in concrete.

2. Utilization of Limestone Aggregates in Concrete Production

Stone quarries are gaining importance for aggregate production day by day. In Turkey, aggregate production is mostly made from sedimentary rocks (such as limestone, dolomite, sandstone) and a small number of igneous rocks (granite, syenite, diorite, gabbro, rhyolite, andesite, trachyandesite, basalt). The physical and chemical characteristics of the aggregates significantly affect the performance, strength, and durability of the concrete. Therefore, physical properties, chemical composition, the mineralogical structure of aggregates to be used in concrete should be examined and their compatibility with related standards should be tested (Yılmaz and Arioğlu 2006). Limestone aggregates are a good aggregate source for concrete production with high strength and density, low porosity (<1%) (West 1998, McNally 1998, Aquino et al. 2010). Another reason why limestone aggregates are preferred as concrete aggregates is their low thermal expansion (French 1991) and the ability to make a good chemical bond with cement paste (Akman 1984, Baradan 2004). A photo of limestone aggregate (LS1), one of the limestone aggregates used in the present study, is presented in Figure 1.



When the studies in the literature are examined, many researchers have investigated the parameters affecting the concrete quality by using limestone aggregates in concrete production. High quality

Figure 1. The LS1 aggregates: (a) coarse, (b) medium, (c) fine

concrete aggregates can be produced from natural rocks such as granite, black and white limestone, syenite, and basalt. The aggregate to be used in concrete should not be easily broken, abraded quickly, and should be in a solid and hard structure (Tunç 2018a). Limestone is mainly composed of calcium carbonate, dense and hard ones are one of the most suitable rock types for concrete production (Murdock and Brook, 1979). In Radonjanin et al. (2013), hardened concrete properties of concrete produced with recycling aggregate were investigated. For this purpose, silica fume, metakaolin, fly ash, and limestone powder were used reducing the amount of cement. Özbek (2016) investigated the usability of five different limestone aggregates in concrete production. Fraj and Idir (2017) examined the change in compressive strength of concrete by using 20%, 50%, and 100% limestone aggregates instead of recycling aggregates.

3. Materials and Method

3.1 Materials

In this study, limestone aggregates (LS1 and LS2) with different properties were used. The physical properties of these aggregates are presented in Table 1. According to TS 802, grain size curves of LS1 and LS2 aggregate mixtures are between A32-B32 standard curves. In this respect, LS1 and LS2 limestone aggregates can be used in concrete production. These aggregates are classified in three separate dimensions. In the aggregate classes used, the aggregates were made ready for use by sieving between 0-8 mm for fine aggregate, 8-16 mm for medium aggregate and 16-31.5 mm for coarse aggregate.

Table 1. Physical properties of LS1 and LS2 aggregates.

Limestone aggregates	Saturated surface dry specific weight (g/cm ³)			Water absorption ratios (%)		
	(S_{dyk}^{coarse})	(S_{dyk}^{medium})	(S_{dyk}^{fine})	(S_a^{coarse})	(S_a^{medium})	(S_a^{fine})
LS1	2.56	2.60	2.65	0.4	0.5	1.2
LS2	2.61	2.64	2.69	1.4	1.5	1.8

where; S_{dyk}^{coarse} = rough aggregate saturated surface dry unit volume weight, S_{dyk}^{medium} = medium aggregate saturated surface dry unit volume weight, S_{dyk}^{fine} = fine aggregate saturated surface dry unit volume weight, S_a^{coarse} = rough aggregate water absorption ratio, S_a^{medium} = medium aggregate water absorption ratio, S_a^{fine} = fine aggregate water absorption ratio.

In the present study, CEM I 42.5 N Portland cement was used. The specific weight of the cement is 3.05 g/cm³ and the Blaine specific surface area is 3490 cm²/g. The initial setting time of cement is 2.6 h and the final setting time is 3.5 h. In addition, the compressive strength of cement mortar was determined as 25.8 MPa, 38.1 MPa, and 49.1 MPa for 2 days, 7 days, and 28 days in accordance with TS EN 197-1.

3.2 Experimental Method

Within the scope of the study; concrete mixtures containing limestone aggregates of different properties have been prepared for different water to cement ratios and different cement contents. For this purpose, LSC1 and LSC2 concrete mix with w/c=0.50, 0.60, and C=300, 400 kg/m³ were obtained by using LS1 and LS2 limestone aggregates. The prescriptions of the prepared concrete mixtures are presented in Table 2.

With the mixture design given in Table 2, LSC1 and LSC2 concrete mixtures were prepared by using a mixer. In order to determine the fresh concrete properties according to TS EN 12350-2, a cut-down funnel was used. Each layer of concrete mixture filled into the funnel in 3 stages was compressed by swelling 25 times. After the top surface was leveled with a trowel, the funnel was pulled upwards at a constant speed.

Table 2. The prescriptions and slump values for LSC1 and LSC2 concrete mixtures.

	Cement (kg/m ³)	w/c	Coarse (kg/m ³)	Medium (kg/m ³)	Fine (kg/m ³)	Slump value (cm)
LSC1	300	0.50	675.5	238.5	1050.2	5.0
	300	0.60	664.6	198.6	1022.0	8.5
	400	0.50	590.3	229.6	927.7	11.5
	400	0.60	564.5	188.0	891.3	23.0
LSC2	300	0.50	800.9	99.8	1095.4	4.0
	300	0.60	771.4	84.7	1060.7	8.0
	400	0.50	706.2	88.6	982.0	10.5
	400	0.60	667.8	83.2	920.4	14.5

The distance between the top surface level of the funnel. It was observed that the slump values of the concrete specimens (LSC1 and LSC2) increased with increasing cement content and water to cement ratio. For the determination of hardened concrete properties of LSC1 and LSC2, 56 pieces of 150×150×150 mm cubic specimens were prepared (Figure 2).



Figure 2. 150×150×150 mm cubic specimens used in the experiments.

The specimens were placed in the curing pool at a temperature of 23±2 °C and removed from the pool at the end of day 28. Compressive strength tests

were performed on 32 cubic specimens of 150×150×150 mm dimensions that dry the surface in accordance with TS EN 12390-3 standard and splitting tensile strength tests of 24 cubic specimens of 150×150×150 mm dimensions in accordance with TS EN 12390-6 standard (Figure 3).

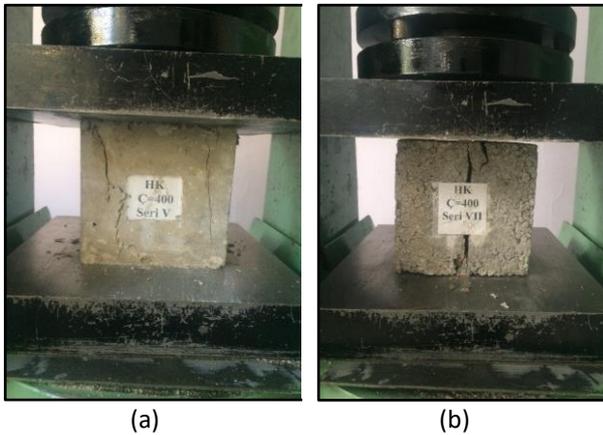


Figure 3. The tests for the determination of hardened concrete properties: (a) Compressive strength test; (b) Splitting tensile strength test.

4. Assessment of Experimental Results

The results of this study, in which the influence of cement content and water to cement ratio on concrete strength were investigated, are presented in this section. In the present study, a series of LSC1 and LSC2 concrete specimens were prepared for different cement contents and water to cement ratios using the limestone aggregates (LS1 and LS2) with different properties. The compressive strength and splitting tensile strength test results of these specimens are presented in Figure 4-7. In Figure 4a, 3 LSC1 concrete specimens were produced using LS1 aggregate for $w/c=0.50$ and $C=300 \text{ kg/m}^3$ and 4 LSC2 concrete specimens were produced using LS2 aggregate. It was measured that there was an average difference of 4% between the compressive strength of LSC1 specimens and an average of 8% between the compressive strength of LSC2 specimens. This is thought to be due to experimental error due to conditions during specimen preparation. However, it was found that the compressive strength of LSC1 concrete specimens was approximately a mean of 5% higher than the compressive strength of LSC2 specimens. Although the aggregate types used in these

specimens have different properties, the difference between the compressive strengths is small because they are the same type of aggregate. In Figure 4b, 4 LSC1 concrete specimens and LSC2 concrete specimens were produced by using LS1 and LS2 aggregates for $w/c=0.60$ and $C=300 \text{ kg/m}^3$. It has been measured that the compressive strength of LSC1 and LSC2 specimens are less than approximately 1%. This indicates that a minimum error has been made during specimen preparation. However, the compressive strength of LSC1 concrete specimens was found to be approximately 1.3% higher than the compressive strength of LSC2 specimens. Although aggregate types used in these specimens have different properties, the difference between the compressive strengths is small because they are the same type of aggregate. However, with the increase of water to cement ratio, it was determined that the compressive strengths decreased by approximately 11% for LSC1 and approximately 8% for LSC2.

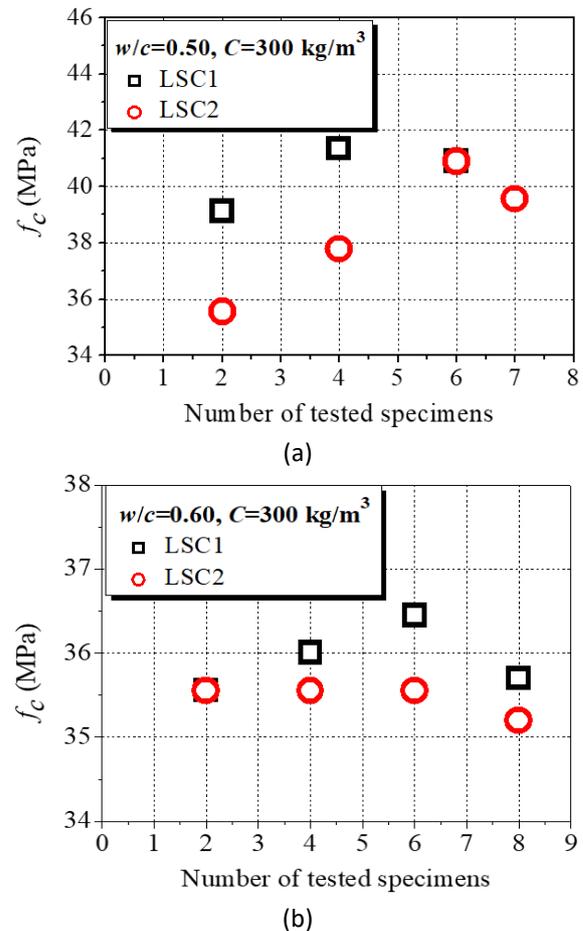


Figure 4. Compressive strength values for $C=300 \text{ kg/m}^3$: a) $w/c=0.50$, b) $w/c=0.60$.

In Figure 5a, 4 LSC1 concrete specimens and LSC2 concrete specimens were produced by using LS1 and LS2 aggregates for $w/c=0.50$ and $C=400 \text{ kg/m}^3$. It has been measured that there is approximately 4% difference between the compressive strengths of LSC1 specimens and approximately 10% between the compressive strengths of LSC2 specimens. This is thought to be due to experimental error due to conditions during sample preparation. This indicates that some errors were made during sample preparation. However, it was determined that the compressive strength of LSC1 concrete specimens was approximately 3% higher than the compressive strength of LSC2 specimens. Although aggregate types used in these specimens have different properties, the difference between the compressive strengths is small because they are the same type of aggregate. In Figure 5b, 4 LSC1 concrete specimens and LSC2 concrete specimens were produced by using LS1 and LS2 aggregates for $w/c=0.60$ and $C=400 \text{ kg/m}^3$. It was measured that there was an average difference of 4% between the compressive strengths of LSC1 specimens and an average of 6.5% between the compressive strengths of LSC2 specimens. This difference rate due to experimental error due to conditions during sample preparation is relatively low. This indicates that some errors were made during specimen preparation. However, it was found that the compressive strength of LSC1 concrete specimens was approximately 4% higher than the compressive strength of LSC2 specimens. Although aggregate types used in these specimens have different properties, the difference between the compressive strengths is small because they are the same type of aggregate. However, with the increase of water to cement ratio, it was determined that the compressive strength of LSC1 and LSC2 decreased by approximately 14% on average.

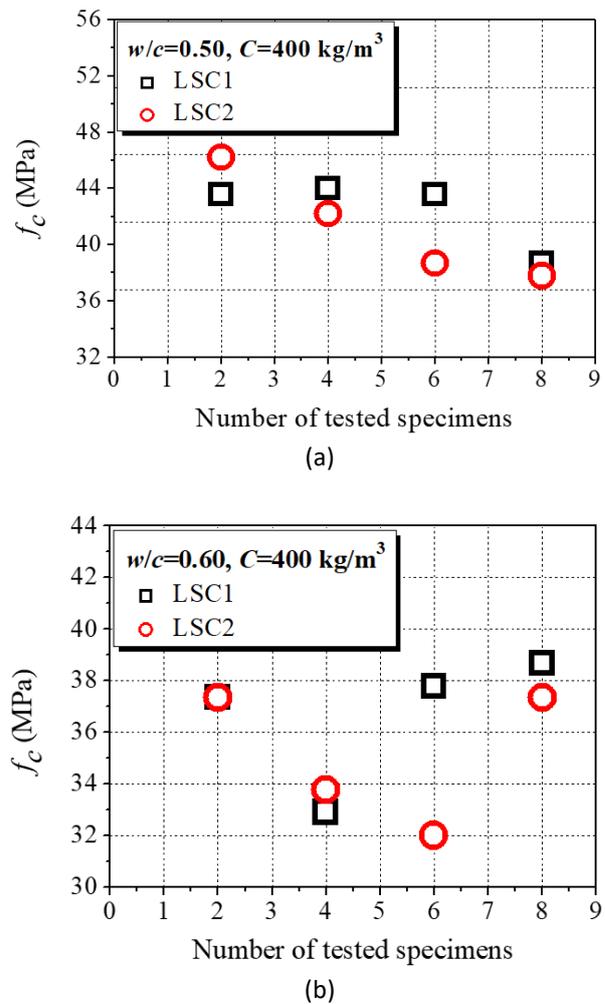


Figure 5. Compressive strength values for $C=400 \text{ kg/m}^3$: a) $w/c=0.50$, b) $w/c=0.60$.

In Figure 6a, 3 LSC1 and 3 LSC2 specimens were produced by using LS1 and LS2 aggregates for $w/c=0.50$ and $C=300 \text{ kg/m}^3$. It was measured that the average splitting tensile strength of LSC1 specimens was 16% and the mean splitting tensile strength values of LSC2 specimens was approximately 7%. This is thought to be due to experimental error due to conditions during sample preparation. This indicates that a mistake was made during specimen preparation. In addition, it is seen that the percent difference in splitting tensile strength result is higher than the percent difference in compressive strength test results. However, the splitting tensile strength of the LSC1 concrete specimens was found to be approximately 10% higher than the splitting tensile strength of the LSC2 specimens. In Figure 6b, 3 LSC1 concrete specimens and 3 LSC2 concrete specimens were prepared by using LS1 and LS2 aggregates for $w/c=0.60$ and $C=300 \text{ kg/m}^3$. It was determined that the splitting

tensile strengths of the LSC1 specimens were approximately 13% and the compressive strengths of the LSC2 specimens were not different. This indicates that no experimental errors were made during the preparation of LSC2 specimens. However, the splitting tensile strength of LSC1 concrete specimens was found to be approximately 18% higher than the splitting tensile strength of LSC2 specimens. It is seen that the increase in splitting tensile strength is higher than the increase in compressive strength. However, with the increase of the water to cement ratio, it was determined that the splitting tensile strengths decreased by approximately 6% for LSC1 specimens and approximately 13% for LSC2 specimens.

and the average splitting tensile strength of LSC2 specimens is approximately 6%. This is thought to be due to experimental error due to conditions during sample preparation. However, the splitting tensile strength of LSC1 concrete specimens was found to be approximately 23% higher than the splitting tensile strength of LSC2 specimens. In Figure 7b, 3 LSC1 concrete specimens and 3 LSC2 concrete specimens were produced by using LS1 and LS2 aggregates for $w/c=0.60$ and $C=400 \text{ kg/m}^3$. It was determined that the splitting tensile strengths of the LSC1 specimens were approximately 9% and the compressive strengths of LSC2 specimens were approximately 15%. This is an indication of experimental error during the preparation of the specimens. However, the splitting tensile strength values of the LSC1 concrete specimens was found to be approximately 10% higher than the splitting tensile strength values of the LSC2 specimens. However, with the increase of water cement ratio, it was determined that the tensile strengths of the splits decreased by approximately 21% for LSC1 specimens and by approximately 11% for LSC2 specimens. It was determined that both compressive strength and splitting tensile strength values of all tested specimens increased with increasing cement content.

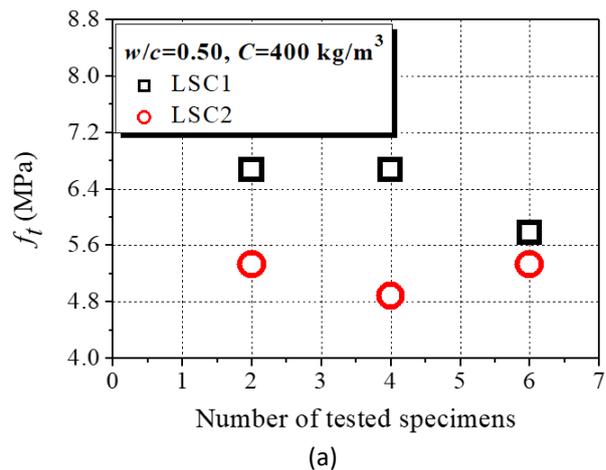
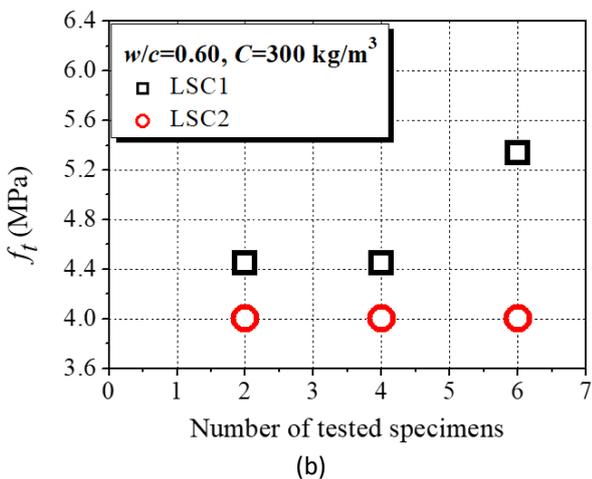
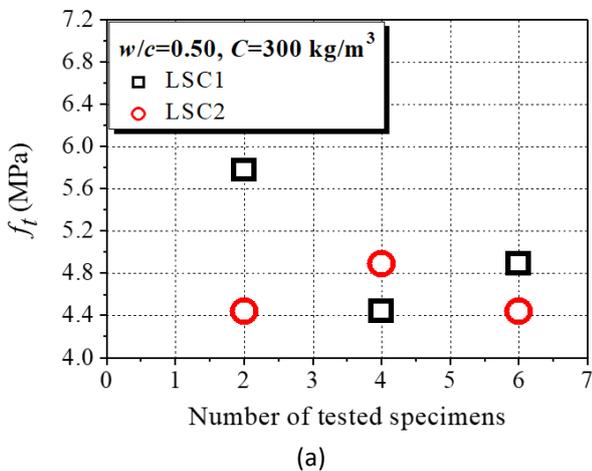


Figure 6. Splitting tensile strength values for $C=300 \text{ kg/m}^3$: a) $w/c=0.50$, b) $w/c=0.60$.

In Figure 7a, 3 LSC1 concrete specimens and 3 LSC2 concrete specimens were prepared by using LS1 and LS2 aggregates for $w/c=0.50$ and $C=400 \text{ kg/m}^3$. It has been measured that the average splitting tensile strength of LSC1 specimens is approximately 10%

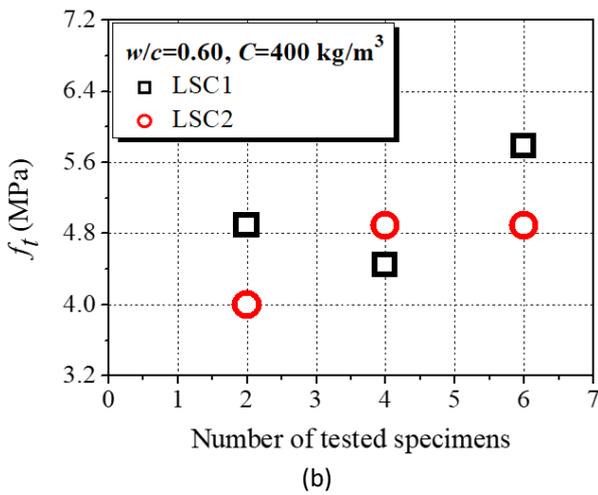


Figure 7. Splitting tensile strength values for $C=400 \text{ kg/m}^3$: a) $w/c=0.50$, b) $w/c=0.60$.

In Figure 8, the relationship between the compressive strength of LSC1 and LSC2 specimens is presented. A linear relationship was determined between the f_c values of LSC1 specimens and the f_c values of LSC2 specimens. The correlation coefficient was determined as $R^2=0.87$. It was determined that the f_c values of LSC1 specimens were approximately 3% higher than the f_c values of LSC2 specimens.

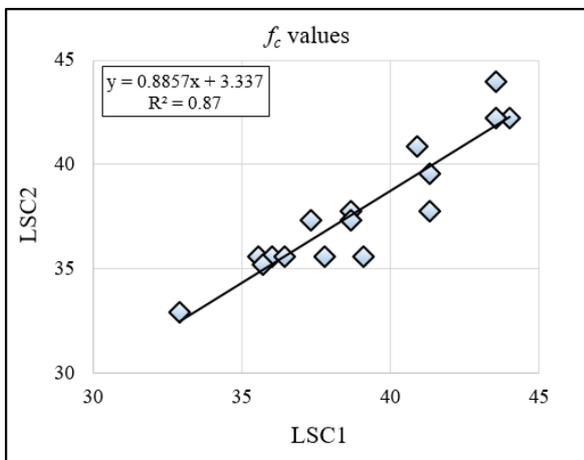
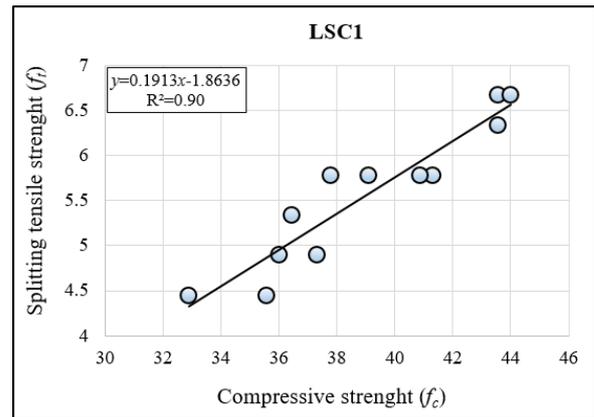


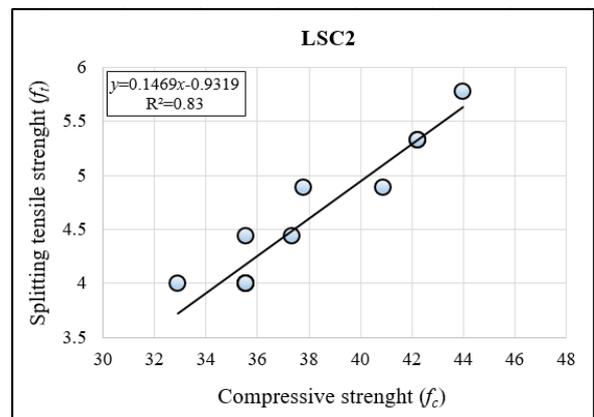
Figure 8. The relationship between compressive strength (f_c) values of LSC1 and LSC2 specimens.

In Figure 9, the compressive strength (f_c) values obtained from the present study and the splitting tensile strength (f_t) values are presented. It is determined that there is a linear relationship between f_c and f_t values for LSC1 specimens. The correlation coefficient was determined as $R^2=0.90$ (Figure 9a). This indicates that there is a good fit

between f_c and f_t values. In addition, it was observed that f_t increased up to approximately 50% with increasing f_c up to about 38%. In Figure 9b, it is determined that there is a linear relationship between f_c and f_t values for LSC2 specimens. The correlation coefficient was determined as $R^2=0.83$. This indicates that there is a good fit between f_c and f_t values. In addition, it was observed that f_t values increased up to approximately 45% with increasing f_c up to about 38%.



(a)

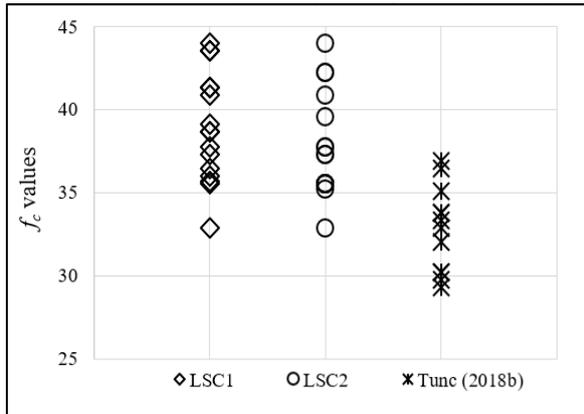


(b)

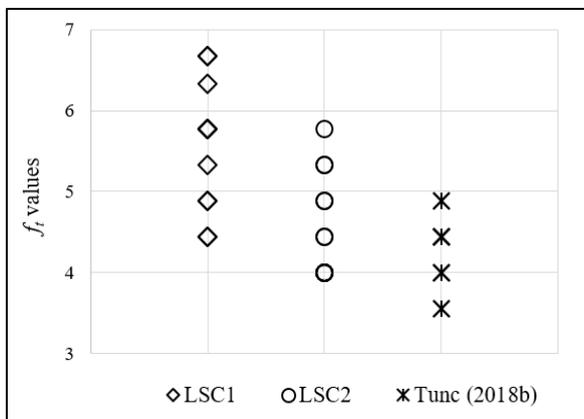
Figure 9. The relationship between f_c and f_t values: a) for LSC1 specimens, b) for LSC2 specimens.

The compressive strength values obtained in Tunc (2018b), where the effect of natural aggregates on concrete strength was examined, were compared with the compressive strength values of LSC1 and LSC2 specimens tested in the present study (Figure 10a). In addition, splitting tensile strength values were compared (Figure 10b). According to this; It was determined that LSC1 specimens were approximately 19% higher than the compressive strength of the specimens tested in Tunc (2018b)

and LSC2 specimens were approximately 15% higher than the compressive strength of the specimens tested in Tunc (2018b).



(a)



(b)

Figure 10. The comparison of present study data with Tunc (2018b) study data: a) for f_c values, b) for f_t values.

5. Conclusions

The conclusions are presented below.

- In this experimental study, the compressive strength and the splitting tensile strength values of the concrete specimens were measured by utilization of the limestone aggregates with different aggregate properties that were used and other mixing ratios were kept constant.
- There was a slight difference between the compressive strengths of the specimens produced with the limestone aggregates having different properties.
- It was determined that both compressive strength and splitting tensile strength increased with increasing cement content.

- It was determined that compressive strength and splitting tensile strength values decreased with increasing water to cement ratio.
- As it is understood that both compressive strengths and splitting tensile strength values of the concrete specimens produced with the present limestone aggregates are found to be appropriate according to the relevant standards, it is concluded that these aggregates will be suitable for use in concrete production.
- A good correlation was determined between the compressive strength and splitting tensile strength.

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