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Effects of Rice Husk on the Lightweight Concrete Properties Produced by Natural Zeolite for Agricultural Buildings

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ABSTRACT— ***The objective of this research was to investigate physical, mechanical and thermal properties of concrete produced by using zeolite (clinoptiolite) and organic waste (rice husk). The lightweight concrete of 300 and 400 cement contents were produced by adding various amounts (5, 10, 15 and 20 %) of rice husk into the zeolite. The physical, mechanical and thermal properties of the samples were determined after 28 days. According to the experimental results, the compressive strengths of the samples for 300 and 400 cement contents ranged between 145.80 and 132.87 kg/cm^2 and between 192.54 and 167.16 kg/cm^2, respectively. The unit weights of the samples for 300 and 400 cement contents ranged between 1406 and 1507 kg/m^3 and 1559 and 1604 kg/m^3, respectively. The water absorption rates of the samples for 300 and 400 cement contents were between 6.17 and 14.19 % and between 4.44 and 7.46%, respectively. In addition, thermal conductivities varied between 0.581 and 0.510 W/mK for 300 cement content and 0.658 and 0.621 W/mK for 400 cement content. In conclusion, rice husk has potential as a material to produce lightweight concrete when considering its strength, resistance and insulation properties.***

Keywords— Lightweight concrete, organic waste, physical and mechanical properties, thermal properties

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1. INTRODUCTION

In concrete construction, the concrete represents a very large proportion of the total load on the structure, and there are clearly considerable advantages in reducing its density. One of the ways to reduce the weight of a structure is the use of lightweight concrete (LWC) [1].The demand for lightweight concrete in many applications for construction is increasing, owing to the advantage of high strength/weight ratio, good tensile strain capacity, low coefficient of thermal expansion due to the voids present in the lightweight aggregates and low density that is favorable for a reduction of load-bearing elements and the size of the foundation [2]. The lightweight concretes are cementitious conglomerates with a density (ranging between 300 and 2000 kg/m^3) sensibly lower than that of an ordinary concrete (usually between 2200 and 2600 kg/m^3). On the basis of their dry bulk density and compressive strength, both evaluated after an aging period of 28 days, lightweight concrete can be classified as follows [3].

Thermo insulating lightweight concretes: Dry bulk density is 300-800 kg/m^3, compressive strength is 5-71 kg/cm^2 (0.49-6.96 MPa). Preferentially it can be used as filling material or insulating coatings.

Low strength lightweight concretes: Bulk density ranges between 800 and 1400 kg/m^3 while compressive strength between 71 and 180 kg/cm^2 (6.96- 17.65 MPa). They are prevailingly used in structures which do not require particular performances from a static point of view. At the same time, they guarantee an acceptable level of thermal comfort.

Structural Lightweight concretes: Bulk density changes between 1400 and 2000 kg/m^3 whereas compressive strength is >180 kg/cm^2 (>17.65 MPa). These concretes, usually manufactured with artificial inert, are used for the production of low density reinforced structures.

The lightweight concretes were classified by the American Concrete Institute (ACI) Committee into three categories according to its strength and density. The first category is termed low strength, corresponding to low density, and is mostly used for insulation purposes (unit weight: <1000 kg/m^3, compressive strength: 7-20 kg/cm^2 [0.69-1.96 Mpa]). The second category is moderate strength and is used for filling and block concrete (unit weight: 1000-1500 kg/m^3, compressive strength: 20–160 kg/cm^2 [1.96-15.69 Mpa]. The third category is structural LCW and is used in reinforced concrete (unit weight: 1500-2000 kg/m^3, compressive strength: 170–410 kg/cm^2 [16.67-40.20 Mpa]) [4].

There are numerous methods in lightweight concrete production. The most popular method is based on using of natural, synthetic or organic lightweight aggregates. Some of the lightweight aggregates are pumice, coal slag, flying ash, zeolite, rice husk, straw, sawdust, cork granules, wheat husk, coconut fiber and coconut shell.

Natural zeolite is a new source for construction and building materials. As a type of crystalline alumino-silicate, zeolite has a three-dimensional structure composed by Si-O tetrahedroids and Al-O tetrahedroids. With the variance of the mole ratio Si/Al, inter connected micro pores of different sizes were formed within the three dimension structural skeleton with a large specific surface area. Using of zeolite in the concrete production can prevent bleeding, segregation and delamination of fresh concrete so as to make pumping process easier, decrease permeability of hardened concrete, enhance durability especially the resistance to alkali aggregate reaction, increase concrete strength and minimize cracking caused by self shrinkage in high performance concrete [5].

Sisman et al [6] were determined that the compressive strengths and oven dry unit weights of the lightweight concrete produced using different rates of natural zeolite (clinoptilolite) and normal concrete aggregate changed between 136 and 235 kg/cm^2 (1.36 - 23.04 MPa) and between 1500 and 1900 kg/m^3, respectively. All produced concretes were resistant to freezing. Water absorption rates of the concretes were below 8%. In addition, thermal conductivities varied from 0.58 to 0.93 W/mK.

The organic wastes that have been used in lightweight concretes are mainly of plant origin and include rice husk, straw, sawdust, cork granules, wheat husk, coconut fiber and coconut shell [7, 8]. By using plant wastes found abundantly in rural areas, it may be possible to construct cheaper and good quality agricultural constructions. Because farm buildings are one or two floors and they carry low load, isolation and low cost are more important than strength [9, 10].

Rice husk, as an organic waste, is a significant problem in rice-cultivating areas because it is not used profitably and is generally burned after harvest, which causes environmental problems. As other rice cultivating country, Turkey has also the same problem. Moreover the Ministry of Environment and Forestry prohibited burning RH. Farmers claim that after rice production has finished, RH is their main problem in preparing seed beds for future crops to be grown. The animal production is also intensified in the region. Use of RH in concrete production for animal housing may solve this environmental problem and provide an advantage in producing lightweight and low-cost concrete. More than half of the rice production in Turkey occurs in the Thrace region. The aim of this study is to examine the effect of RH ,which is a organic waste, on the physical, mechanical and thermal properties of lightweight concrete produced by natural zeolite (clinoptilolite).

2. MATERIAL AND METHODS

The main material used in this study was RH, which was the paddy waste produced in the Thrace region. Furthermore, mixed coarse aggregate passed through an 8 mm (0.31 in.) sieve, natural zeolite (clinoptilolite) and ASTM Type I (PC 42.5) Portland cement were used as binding materials. The chemical composition and physical properties of the zeolite and cement used in this study are given in Tables 1 and 2, respectively.

Table 1. Chemical Composition and Physical Properties of Natural Zeolite (clinoptilolite)

Material Properties	Natural Zeolite	
	Slight	Coarse
SiO_2 (%)	71.0	
CaO (%)	3.40	
Fe_2O_3 (%)	1.70	
ZAl_2O_3 (%)	11.80	
K_2O (%)	2.40	
MgO (%)	1.40	
Loose Unit Weight (kg/m^3)	1196	1131
Condensed Unit Weight (kg/m^3)	1326	1205
Spesific Gravity (g/cm^3)	1.65	1.70
Water Absorption (%)	19	18

Table 2. Chemical Composition and Physical and Mechanical Properties of The Cement

Chemical Composition		Physical and Mechanical Properties		
Component	%			
Insolube Residues	0.52	Spesific Gravity (gr/cm^3)		3.14
		Setting Time	Initial (min)	137
SO$_3$	3.11		Final (min)	194
		Soundness (Le Chatelier) (mm)		1
Loss on Ignition	1.25	Spesific Surface (cm^2/g)		3700
		Compressive Strength (kg/cm^2)	2 day	271
Cr	0.0385		7 day	416
			28 day	569

The grading curve of natural zeolite used in lightweight concrete and standards values [11] are given Figure 1. As it can be seen from Figure 1, the grading curve for zeolite remained within the limits specified by TS 1114 EN 13055-1 [11], Turgutalp and Orung [12] and Erdogan [13].

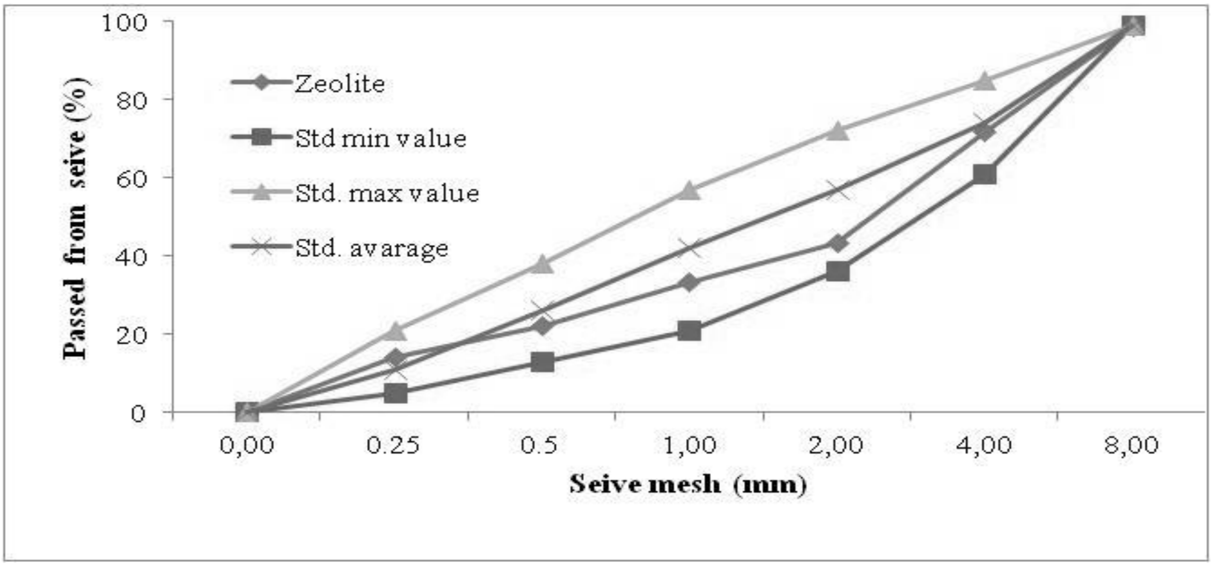

Figure 1. Grading Curves of the Zeolite

To prepare the lightweight concrete material samples, nominal mixing techniques were applied because of the organic origin of RH [14]. Organic material contents of the aggregate decrease the compressive strength [15]. Therefore, the RH ratio of the mix was fixed at values less than 40%. The RH was obtained from the Ipsala district in the Thrace region of Turkey. The RH used in the mixtures was soaked with water for approximately 30 min because the RH had high water absorption.

Based on weight the natural zeolites were mixed thoroughly in a dry state. Then, the zeolite was replaced with the RH at ratios of 0 (ZC300), 5 (ZC305), 10 (ZC310), 15 (ZC315) and 20 (ZC320) for 300 cement content and 0 (ZC400), 5 (ZC405), 10 (ZC410), 15 (ZC415) and 20 (ZC420) for 400 cement content by volume. The ZC300 and ZC400 concrete classes were the control concretes. The cement contents in the mixture for all concrete classes were kept constant between 300 and 400 kg/m^3. Water amounts in the mixtures were determined according to slump because of high water absorption of the zeolite (approximately 20%). The slump value in the mixture for all concrete classes were kept constant at 50±10 mm [6, 12].

Concrete test samples were cubic 150 mm x 150 mm x 150 mm. All the test samples were molded and held for 1 day and then cured in a water tank at 20 ± 2 ºC until the 6th and 27th days according to TS EN 12390-2 [16]. The samples for each lightweight concrete class were tested and examined for physical and mechanical properties. The compressive strength according to TS EN 12390-3 [17], unit weight according to TS 3624 [18], the water absorption rate according to TS 3624 [18], freezing-thawing resistance [19] and thermal conductivity according to TS EN 1946-1 [20] were determined after 28 days according to standarts. To evaluate the reproducibility of the results, all measurements were conducted on three samples.

Ten different mixture compositions (ZC300 to ZC420) were examined in this study, and their mixture proportions and fresh concrete consistency are given Table 3.

Table 3. Mixture Proportions

Mixture	Cement (kg/m^3)	Coars Zeolite (kg/m^3)	Slight Zeolite (kg/m^3)	RH (L/m^3)	Water (kg/m^3)	W/C	Slump (mm)
ZC300	300	627	585	0	426	1.42	50
ZC305		589	543	35.48	414	1.38	47
ZC310		555	508	70.98	414	1.38	53
ZC315		524	480	106.5	390	1.30	43
ZC320		489	443	141.95	345	1.15	57
ZC400	400	540	498	0	443	1.11	51
ZC405		513	473	30.88	439	1.10	56
ZC410		486	448	61.76	402	1.01	57
ZC415		459	423	92.64	396	0.99	48
ZC420		432	398	123.52	387	0.97	58

3. RESULTS AND DISCUSSION

The experimental results on the characteristics of the fresh and hardened concrete are presented in Tables 4.

3.1. Unit weight

According to the obtained data, the unit weight of the 28-day hardened samples for 300 and 400 cement contents decreased with increasing RH content because the specific gravity of RH was lower than that of the zeolite (Table 4). The highest unit weight at day 28 for 300 and 400 cement contents were 1507 kg/m^3 (ZC300) and 1604 kg/m^3 (ZC400), respectively and the lowest values for 300 and 400 cement contents were 1406 kg/m^3 (ZC320) and 1559 kg/m^3 (ZC420), respectively. The relationship between the unit weight and the amount of RH is shown in Figure 2. While unit weights in the first tree mixtures (ZC300-ZC305-ZC310 and ZC400-ZC405-ZC410) for both cement contents decreased minimally, the other mixtures decreased more than these ones. These results shows that the reducing of the unit weight increase with increasing of RH amount in the mixture. Sisman et al.[21] found that unit weight of the concrete produced by rice husk decreased by 20% when compare to normal concrete, from 2268 kg/m^3 to 1797 kg/m^3

Table 4. Physical and Mechanical Properties of The Concretes at Day 28

Mixture	Dosage kg/m^3	Unit-Weight kg/m^3	Compressive Strength kg/cm^2	Water Absorption %	Freezing-Thawing Resistance (Compressive strength after freezing-thawing) kg/cm^2	Thermal Conductivity W/mK
ZC300	300	1507	145.80	6.17	134.67	0.581
ZC305		1497	144.46	6.72	129.20	0.573
ZC310		1484	143.16	8.08	128.73	0.564
ZC315		1445	139.83	11.10	122.98	0.535
ZC320		1406	132.87	14.19	118.59	0.510
ZC400	400	1604	192.54	4.44	174.18	0.658
ZC405		1600	189.09	5.27	170.80	0.652
ZC410		1591	183.82	5.98	164.96	0.647
ZC415		1576	176.46	6.69	156.94	0.635
ZC420		1559	167.16	7.46	147.50	0.621

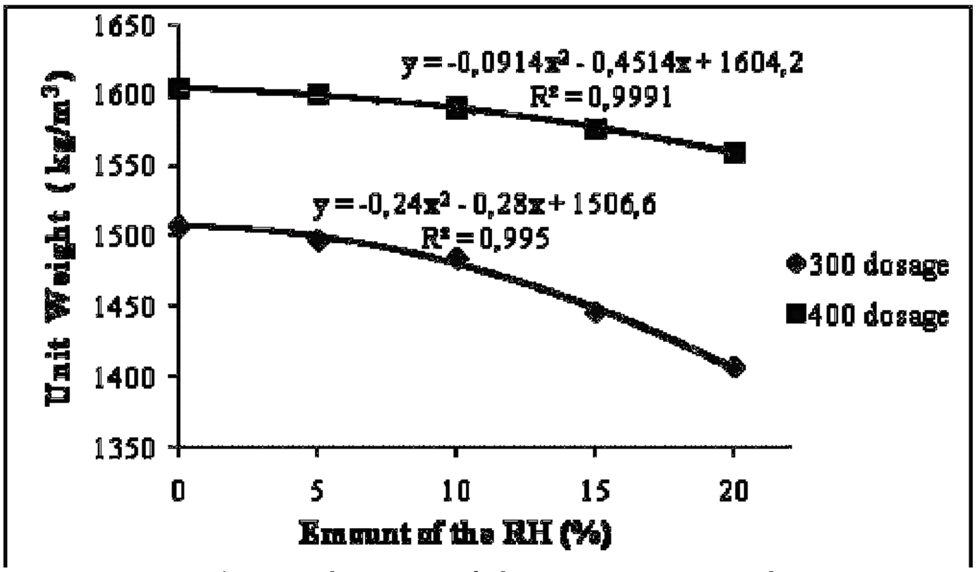

Figure 2. The Amount of The RH Versus Unit Weight

3.2. Compressive strength

The compressive strengths of the samples on day 28 for 300 and 400 cement contents ranged from 132.87 to 145.80 kg/cm^2 (13.03-14.30 MPa) and 167.16 - 192.54 kg/cm^2 (16.39 - 18.88 MPa), respectively (Table 4).

The relationship between the RH content and the compressive strength is shown in Figure 3. The compressive strengths of the samples on day 28 for 300 and 400 cement contents by unit weight, decreased with increasing RH content in the mixtures. Using aggregate replacement with RH contents of 5, 10, 15 and 20 % decreased the 28 day compressive strength by 0.92, 0.90, 2.33 and 4.98 % for 300 cement content and by 1.79, 2.79, 4.00 and 5.27% for 400 cement content, respectively. The adverse effects of RH amount in mixture on compressive strength increase with increasing of its cement content.

The relationship between unit weight and compressive strength after 28 days is shown in Figure 4, which reveals that, there is a polynomial correlation between the compressive strength and the unit weight for lightweight concrete.

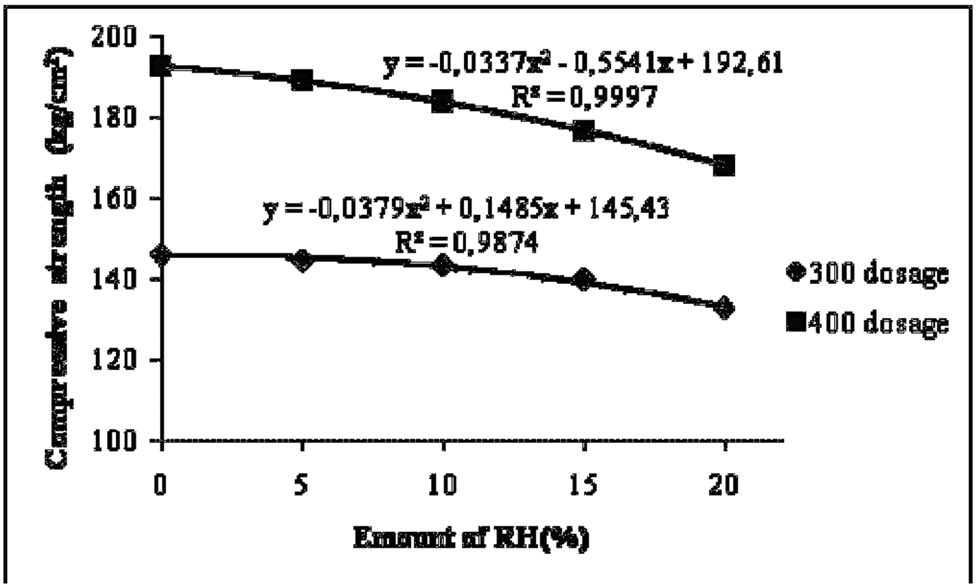

Figure 3. The Effect of RH on The Compressive Strength

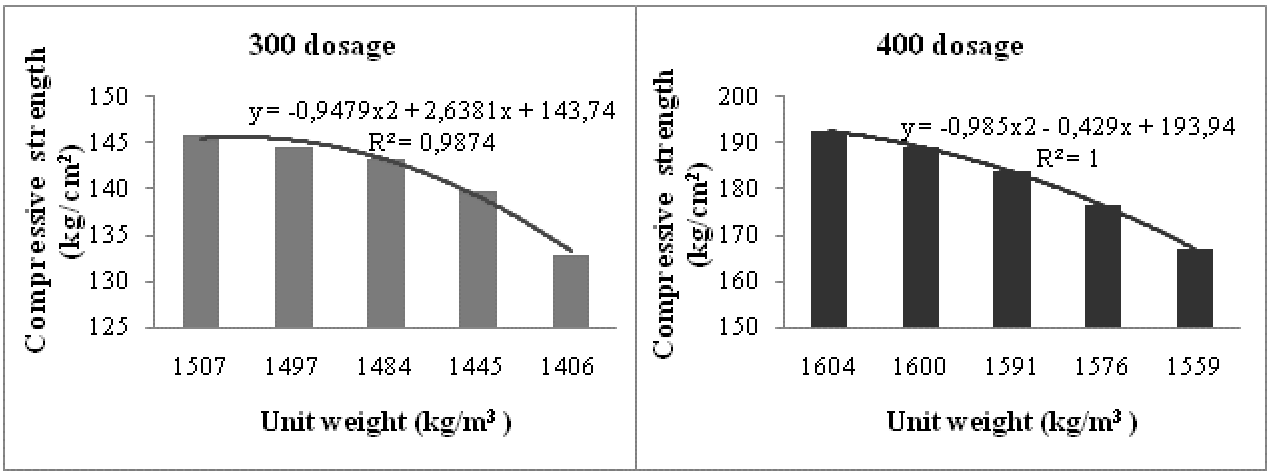

Figure 4. The Compressive Strength Versus Unit Weight

Lightweight concretes are defined as structural lightweight concrete by a minimum compressive strength of 170 kg/cm^2 and a unit weight less than 2000 kg/m^3 and as moderate lightweight concrete by compressive strength of 20-160 kg/cm^2 and a unit weight 100-1500 kg/m^3 by Kosmatka and Panarese [4]. The lightweight concretes produced with a dose of 300 in this study are used for filling and block concrete in structures which do not require particular performances from a static point of view and produced with a dose of 400 are used for the production of low density reinforced structures. Sisman et al. [21] stated that the compressive strengths of the concrete samples produced by RH ranged from 155.0 – 319.1 kg/cm^2 and 184.6 – 382.on days 7 and 28, respectively.

3.3. *Water absorption*

The water absorptions of the samples on day 28 for 300 and 400 cement contents ranged between 6.17 and 14.19 % and between 4.44 and 7.46%, respectively (Table 4). As expected, using the RH as an aggregate replacement resulted in an increase in sample water absorption. The minimum water absorption value was 4.44% for ZC400 and the maximum value was 14.19% for ZC320. The relationship between the RH content and water absorption is shown in Figure 5, which reveals that increasing of the RH in the mixture increased water absorption. But this increase was reduced with increasing of the cement content in the mixture.

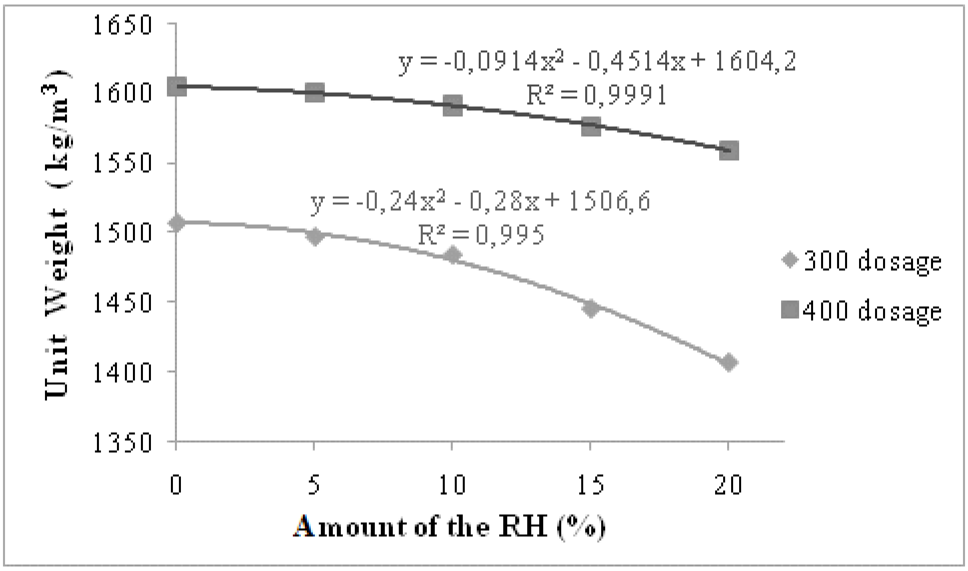

Figure 5. The Relationship Between RH Content and Water Absorption

3.4. Freezing-thawing resistance

The resistance of lightweight concrete to freezing-thawing was determined by examining the changes in the compressive strength. For this reason, compressive strength tests were conducted after each freezing-thawing cycle. The results are presented in Table 4.

As the RH content increased in the mixture, the compressive strength values decreased; this behavior paralleled the resistance behavior before the freezing-thawing cycles. The decreases in compressive strength for 300 and 400 cement contents were greatest ZC320 with 13.83% and ZC420 with 11.76% while the decreases were least ZC300 with 7.63% and ZC400 with 9.53%, respectively in the decreasing order (Table 4). Considering all of the results together, losses in compressive strength due to freezing-thawing cycles remained well below the maximum losses reported by Erdoğan [13] for lightweight concrete. Therefore, according to the standard specifications that state the loss in compressive strength must be less than 20%, it may be concluded that all concrete samples can be qualified as suitable.

3.5. Thermal conductivity

Table 4 shows the variation in thermal conductivity with changing RH ratios. The thermal conductivities of the samples were 0.581, 0.573, 0.564, 0.535 and 0.510 W/mK for 300 cement content and 0.658, 0.652, 0.647, 0.635 and 0.621 W/mK for 400 cement content with RH aggregate replacement values of 0, 5, 10, 15 and 20% by zeolite volume, respectively. The differences among the results are due to the fact that the thermal conductivity is a function of unit weight. Steiger and Hurd [22], Lu-shu et al [23], Blanco et al [24] and Uysal et al [25] reported this relationship between the thermal conductivity and the unit weight of lightweight concrete. They experimentally derived a correlation between the thermal conductivity and the unit weight for lightweight concrete and also reported that the thermal conductivity increased with increasing unit weight. Figure 6 shows the variation in thermal conductivity with the unit weight.

Using a zeolite replacement with RH contents of 5, 10, 15 and 20% decreased the thermal conductivity by 1.38, 1.57, 5.14 and 4.67% for 300 cement content and by 0.91, 0.77, 1.85 and 2.20% for 300 cement content, respectively. Reduction in thermal conductivity depending on the amount of RH for 300 cement content was higher than for 400 cement content. This is because of the increase amount of cement in the mixture.

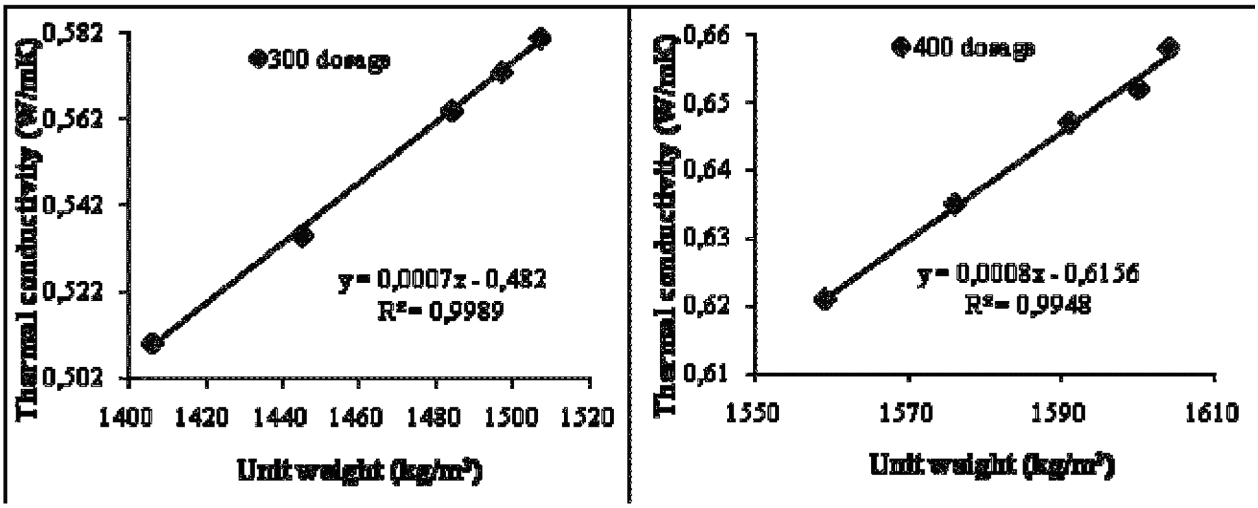

Figure 6. The Relationship Between Thermal Conductivity and Unit Weight

4. CONCLUSIONS

The results indicate the followings:

- The unit weights of the produced lightweight concrete samples on day 28 varied between 1507 and 1406 kg/m^3 for 300 cement content and between 1604 and 1559 kg/m^3 for 400 cement content. All lightweight concretes produced in this study could be classified as structural lightweight concrete with respect to their unit weights.
- The compressive strengths of the samples on day 28 ranged from 132.87 to 145.80 kg/cm^2 (13.03-14.30 MPa) for 300 cement content and from 167.16 to 192.54 kg/cm^2 (18.88-16.39 MPa) for 400 cement content. The lightweight concretes as 400 cement content produced in this study can be defined as structural lightweight concrete when considering their unit weight and compressive strength. The others mixtures can be defined as moderate strength lightweight concrete.
- The water absorptions of the samples on day 28 varied between 6.17 and 14.19 % for 300 cement content and between 4.44 and 7.46% for 400 cement content. The use of RH as an lightweight aggregate replacement increased the water absorption.
- The thermal conductivity decreased with increasing RH content. The thermal conductivity varied between 0.581 and 0.510 W/m K for 300 cement content and between 0.658 and 0.621 W/mK for 400 cement content. This research showed that the thermal conductivity of the RH aggregate lightweight concrete was lower than that of an equivalent lightweight concrete.

According to the experimental results, it can be concluded that structural and insulating concrete can be produced using RH to meet the strength, resistance and insulation requirements, and the produced material can be used in agricultural buildings which are one or two floors and carry low loads

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