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Water Content Distribution of Binary Soil Mixtures

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Abstract

Binary soil mixtures are mostly used for liner materials. The most common binary mixture is compacted sand bentonite mixture; lately compacted zeolite bentonite mixture is also proposed. The major difference between sand and zeolite is that, sand is an impervious grain where zeolite is a pervious, microporous grain. Additionally, zeolite holds water whereas sand does not. Thus, when bentonite is blended with zeolite, the mixtures is expected to behave different than it's blended with sand. Unfortunately, this major difference is rarely of interest by researchers and zeolite water content was used to be assumed to be zero like sand. This study investigates the water content distribution of components in binary mixtures namely, zeolite bentonite mixture and sand bentonite mixture. During the tests, it is assumed that sand had no water content. The saturated state water content of zeolite for varying grain sizes was found to be 28% and zeolite and bentonite are found to be in competition to hold water. Test results showed that zeolite water content increases slightly up to the optimum water content of the mixture, reaches a maximum value and then starts to decrease rapidly. The water content of bentonite in zeolite bentonite mixture and sand bentonite mixture is found to be almost the same between the dry of optimum and optimum compaction states and when the mixtures are in wet of optimum compaction state the water content of bentonite in zeolite bentonite mixture is getting to be higher than it is in sand bentonite mixture.

Keywords: Binary mixtures, zeolite, bentonite, water content.

Killi Karışımlarda Su İçeriği Dağılımı

Özet

Killi karışımlar genelde geçirimsiz tabaka amacı ile kullanılmaktadır. Killi karışımların en sık rastlanılanı sıkıştırılmış kum bentonit karışımları olmakla beraber, son zamanlarda sıkıştırılmış zeolit bentonit karışımları da alternatif olarak önerilmektedir. Zeolit ve kum arasındaki en temel fark kum danelerinin geçirimsiz zeolit danelerinin ise geçirimli mikro boşluklu yapıya sahip olmalarıdır. Buna ek olarak zeolit, bünyesinde, kumun aksine, bir miktar su da tutabilmektedir. Bu sebeple, bentonit zeolit karışımının davranışı, bentonit kum karışımının davranışından farklı olması beklenen bir durumdur. Zeolit ve kum arasındaki bu temel farklılık maalesef araştırmacılar tarafından çoğu kez es geçilmiş ve değerlendirmelerde zeolitin su içeriği, kumda olduğu gibi sıfır olarak göz önüne alınmaktadır. Bu çalışmada, zeolit - bentonit ve kum - bentonit karışımlarındaki elemanların su içeriği dağılımları incelenmiştir. Değerlendirme esnasında kumun su içeriği sıfır olarak kabul edilmiştir. Farklı dane çaplarındaki zeolit örneklerinin suya doygun haldeki su içerikleri %28 olarak bulunmuş olup bu durum, zeolitin bentonitle bir karışım halinde iken su içeriği konusunda bu iki zeminin birbirlerinden su alışverişi yapacağını düşündürmektedir. Deney sonuçları, zeolitin su içeriğinin karışımın optimum su içeriğine kadar artış gösterdiğini ve maksimum değere ulaştıktan sonra hızlı bir şekilde azaldığını göstermiştir. Bentonit su içeriği ise zeolit bentonit ve kum bentonit karışımlarının su içerikleri optimumda ve optimum su içeriğinden daha düşük su içeriklerinde neredeyse aynı kalırken; optimumdan daha yüksek su içeriklerinde ise zeolit bentonit karışımlarındaki bentonit su içerikleri, kum bentonit karışımlarındakinden daha yüksek bulunmuştur.

Anahtar Kelimeler: Killi karışımlar, zeolit, bentonit, su içeriği.

1 Introduction

Zeolites have been used in agriculture and industry for years for many applications. Lately, zeolites have been announced for use of liner materials [Mumpton, 1999; Özkirim & Yörükoğullari, 2005; Caputo & Pepe, 2007; Turan & Ergun, 2009; Alver et al., 2010; Özel et al., 2012; Hong et al., 2016]. Consequently, zeolites have blended with bentonites (ZBMs) and tested for their hydraulic conductivities, adsorption capacities and volumetric shrinkage limits [Kayabalı, 1997; Tuncan et al., 2003; Kaya & Durukan, 2004; Turan & Ergun, 2009; Ozel et al., 2012; Hong et al., 2016]. The results of these tests were also compared to an another natural liner material, sand bentonite mixtures (SBMs). In SBMs, it is assumed that, water content of sand in SBMs is negligible and bentonite adsorbs all the water in the mixture. Kenney et al., 1992, proposed a model for determining the water content distribution in SBMs. Due to the very small water holding capacity of sand when compared to bentonite, the authors suggested that in a SBM, the mixture is composed of dry sand and wet bentonite and accepted that the mixture's water content concerns bentonite alone. Depending on this criterion, the water content of bentonite and bentonite void ratio for varying B/S proportions among with the volume proportions of air, water, bentonite and sand in a SBM was determined. Lately, researchers managed to adapt this model to ZBMs. However, there is confusion on the water content of each component in ZBMs. In ZBMs, the condition is somewhat different, due to the water uptake potential of zeolite. Moreover, zeolite holds water physically and lets the water flow in and out freely, while bentonite constitutes chemical and electrical bonds with it. Consequently, water uptake speed of zeolite becomes much quicker than bentonite. This causes insufficient swelling of bentonite in early stages of hydraulic conductivity tests which may also result in preferential flow.

Zeolites are known with their tunnels and cages in their structures, which are rigid when exposed to water [Mumpton, 1999; Kaya & Durukan, 2004; Durukan et al., 2013]. Water can freely move in and out of zeolite body without any structural or volume change. This may affect the water content distribution to the constituents in zeolite bentonite mixtures. Many researchers studied on the water content of bentonite in SBMs and some tried to adapt it to ZBMs. However, these studies were theoretical [Kayabalı, 1997; Ören, 2007; Durukan et al., 2013]. Moreover, it was suggested that zeolite had no water content like sand and so, bentonite had all water in the mixture [Kayabalı, 1997; Kayabalı & Kezer, 1998]. However, it is clear that this is not the case in reality.

In this study, the water content of components in ZBMs and SBMs were determined experimentally and compared to each other. The previous studies done for the determination of the water content of bentonite in a ZBM were analytical because, it is hard to determine the water contents of each material in a compacted mixture sample experimentally. In this study, instant water contents of bentonite before compaction in ZBM and SBM samples were experimentally determined.

2 Materials and Methods

In order to determine the water content distribution, ZBMs and SBMs were prepared at various water contents and left for curing for 24h in a sealed plastic bag just the same as the compaction procedure. After 24 hours, the water contents of the mixtures and bentonite in each mixture were determined. Bentonite content in 10% ZBMs was so little that it was not possible to separate bentonite even from the coarse particles. Due to this reason, water content for each component was determined for 20% and 30% ZBM and SBM samples.

Due to the fine size of sand and zeolite used in compaction and hydraulic conductivity tests, it is almost impossible to separate bentonite from the grains of sand or zeolite. So that, coarse sand and zeolite were needed to be used. However, the grain size might have influenced the water uptake of zeolite. Thus, firstly, the grain size effect on the water content of zeolite was investigated. The zeolite samples composed of different grain sizes, ([–No.200], [No.20 – No.200], [No.10 – No.40], [3/4″ – 3/8″] and block sample) (Figure 1) were kept under water for 24 hours and their water contents were determined. The water contents of these zeolites were determined to be very close to each other. Hence it is concluded that the grain size distribution had no influence, and water content distribution tests were conducted with the grain size having a uniform distribution between 3/4″ and 3/8″ (Figure 2). This grain size interval was selected depending on the allowable maximum grain size for compaction. It should be noted that the water contents given here are instant water contents corresponding to the initial condition before the compaction process.

Figure 1. Zeolite samples at different grain sizes

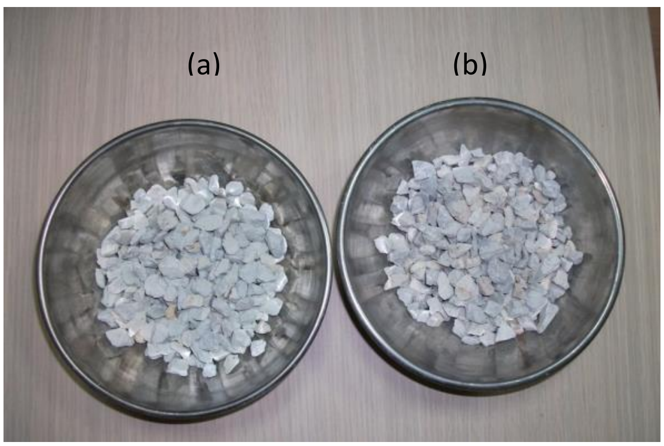

Figure 2. Coarse a) zeolite and b) sand samples used in determining the water content distribution tests

3 Results

The bentonite water contents (w_b) of 20% and 30% SBMs and ZBMs related to the mixture water contents (w_{mix}) are plotted in Figure 3. It is obvious from Figure 3 that, at a given w_{mix} the w_b of ZBMs are lower than that of SBMs due to the water uptake of zeolite. The relation of w_{mix} and w_b of 20% SBMs and ZBMs at their dry of optimum, optimum and wet of optimum water contents (classical ±4% optimum water contents for dry and wet side of optimum water content) are plotted in Figure 4.

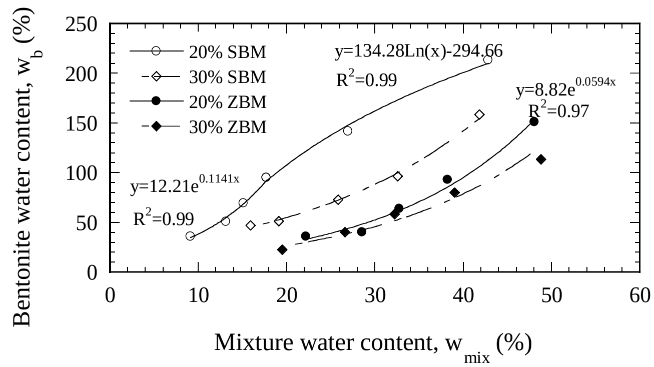

Figure 3: Bentonite water content of 20% and 30% zeolite-bentonite and sand-bentonite mixtures related to their mixture water contents

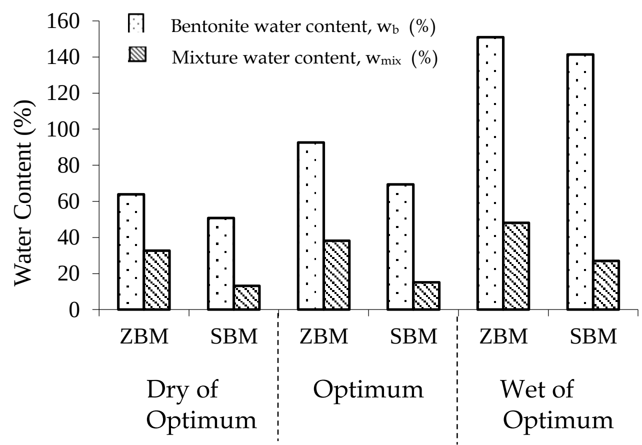

Figure 4: Bentonite water content and mixture water content of 20% zeolite-bentonite and sand-bentonite mixture samples at their dry of optimum, optimum and wet of optimum compaction water contents

When the compaction water contents of the mixtures are compared, both the w_{mix} and the w_b of ZBMs are higher than that of SBMs. However, this may be misleading when the results were not compared as relative to their optimum water contents, due to the difference between the compaction characteristics of SBMs and ZBMs. However, when the proportion of w_b to the w_{mix} is considered, it is seen that the w_b of ZBMs are lower than that of SBMs, when they are related to the w_{mix} (Table 1). The w_b / w_{mix} values of SBMs at their dry of optimum, optimum and wet of optimum compaction water contents are 1.98, 1.90 and 1.67 times higher than that of ZBMs, respectively. This means that, the w_b of ZBMs does not increase as much as the w_{mix} of ZBMs, when compared to those of SBMs due to the water uptake of zeolite.

Table 1 Comparison of w_b related to the w_{mix} of 20% zeolite-bentonite and sand-bentonite mixtures at their dry of optimum, optimum, and wet of optimum compaction water contents

20% mixtures	Dry of optimum		Optimum		Wet of optimum	
	SBM	ZBM	SBM	ZBM	SBM	ZBM
$A = w_b / w_{mix}$	3.87	1.95	4.59	2.42	5.24	3.14
A_{SBM} / A_{ZBM}	1.98		1.90		1.67	

Kayabalı (1997) has calculated the w_b of ZBMs depending on the criteria proposed by Kenney et al. (1992), which assumes that bentonite would have all water in a binary mixture. However, in this study it is proposed that zeolite and bentonite would be in competition for water uptake. Thus, the w_b was determined experimentally and the results were found to be lower than those calculated values given in Kayabalı (1997) (Figure 5). In addition, according to Kayabalı (1997), the water content of bentonite in ZBMs having a BC of lower than 13%, exceeds its liquid limit.

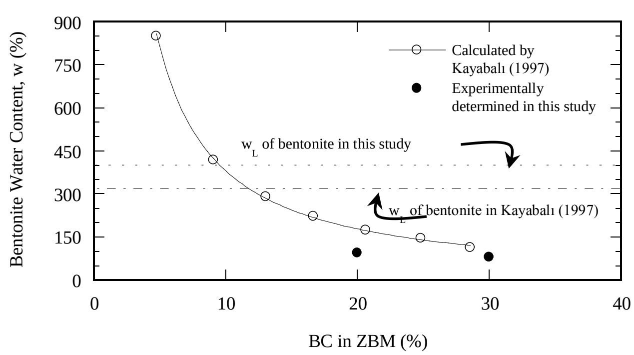

Figure 5: Bentonite water contents of various zeolite-bentonite mixtures at their optimum water contents calculated by Kayabalı (1997) and experimentally determined in this study

The difference between the compaction characteristics of SBMs and ZBMs were also compared by using normalized compaction water contents [Ören et al., 2014]. Similarly, the w_b of SBMs and ZBMs are compared in Figure 6 with respect to the water content relative to the optimum compaction water contents of 20% SBM and ZBM. At -40% water content relative to its optimum compaction water content, w_b of 20% SBM was slightly higher than w_b of 20% ZBM. This slight difference decreases gradually and w_b values of ZBMs and SBMs becomes equal while the mixture water content remains at its -20% water content relative to its optimum compaction water content. At the optimum water content, it is seen that w_b of ZBM was higher than w_b of SBM. While the compaction water increases, it is seen that w_b of ZBM gradually increases more than w_b of SBM. For instance, the w_b of ZBM is 133%, where w_b of SBM is 120% at 20% water content relative to optimum. Nevertheless, the w_b of ZBM is 199%, where w_b of SBM is 179% at 40% water content relative to optimum. The differences between the w_b values of ZBM and SBM are 13% and 20% for 20% and 40% water content relative to optimum, respectively. In addition, zeolite water content (w_z) was calculated and plotted in Figure 6. It is seen that zeolite water content increases slightly up to the optimum water content, reaches a maximum value and then starts to decrease rapidly. It should be noted that the water content of zeolite for varying grain sizes was found to be 28% in average, after 24h soaking beneath water. The w_z of ZBMs are also found to be less than or approximately equal to 28%.

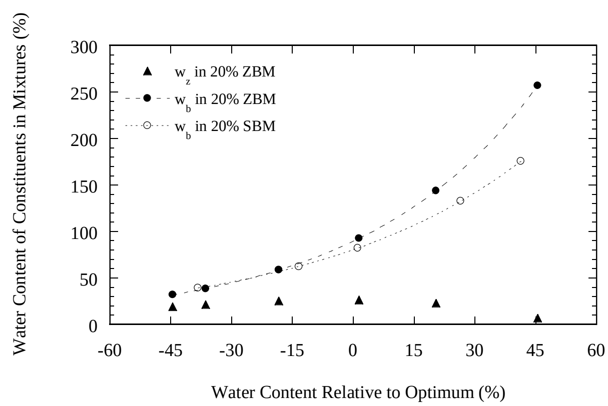

Figure 6: Water content of components in 20% zeolite-bentonite and sand-bentonite mixtures

4 Conclusions

As mentioned before, zeolite holds water in its structure physically, which can be explained by capillary forces, where bentonite constitutes electrical and chemical bonds with water. Thus, by inspection of the data given in Figure 6, it can be assumed that the bonds formed by bentonite exceed the capillary tensions in zeolite at higher water contents. It is probably because of that bentonite swelled enough to separate zeolite grains from each other and bentonite covered each zeolite grain. When the bentonite confines the zeolite grains, the contact of the bentonite to the surface of zeolite grain maximizes which may cause the bentonite to absorb the water held physically by suctions in zeolite grains. The findings of this study supports this imaginary argument, however, validation of this argument needs more intensive investigation including the suctions in zeolites, bentonite water uptake potential, suction characteristics of both zeolite and bentonite and comparison of these for varying water contents.

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