Experimental Study Of Lime Treatment Of a Compacted Swelling Bentonite

Omar Faisal Alzahrani 438010995 Abdulaziz Zaid Althawwad 439014082

Supervised by:

Dr. Riyadh Alturki

Abstract

Optimizing the aggregate gradations and its effects on concrete workability, durability, economy, and sustainability have been an area of greater interest. Many aggregate proportioning methods have been proposed over the last decades to solve aggregate gradation issues and to reduce the cement content while maintaining strength, durability, economy, and sustainability of concrete. The Tarantula Curve is a recently developed aggregate proportioning technique that can evaluate aggregate gradations and can give insights of the issues of bad gradations. Since the Tarantula Curve have been having great success in the United States in producing concrete mixtures with outstanding performances and lower cost, this project aims to investigate the Tarantula Curve proportioning method using local materials in Saudi Arabia and then compare mixtures made by the Tarantula Curve to mixtures made by the ACI-211 method in terms of workability, compressive strength, and cost. The results from this study showed that poor workability occurred in the mixtures as more than 20% of the coarse aggregate retained on a single sieve. In addition, the compressive strength decreased as the 20% limit was exceeded. Similarly, for the fine aggregates, for the mixtures where the limits of sieve sizes #100 and #200 were exceeded, poor workability was observed and a reduction in the compressive strength was noticed. Harsher mixtures were produced as more than 12% of the fine aggregates retained on the sieve size 2.36 mm (#16). When comparing the Tarantula Curve mixtures to the ACI 211 mixtures, the workability of the Tarantula Curve mixtures is lower due to the lower amount of cement, but it was enhanced with the use of water-reducers (WR). The Tarantula Curve produce mixtures with a 35% higher in compressive strength in comparison to the ACI 211 mixtures. In terms of cost, the Tarantula Curve produced concrete mixtures that cost 6% less compared to the ACI 211 mixtures.

Introduction

Concrete is a construction material used worldwide extensively due to its strength, durability, and availability of its raw materials. The core compositions of concrete are cement, aggregates, and water. Plus, minerals and admixtures are added to enhance certain properties such as strength and workability. The consumption of concrete in construction industries has increased dramatically over the last decades. Currently, concrete is consumed at a rate of 4.4 billion tons annually. Based on the Chatham House Report, this rate is expected to elevate to above 5.5 billion ton by 2050 because of large urbanization around the world [1]. Cement in concrete is the most expensive ingredient due to the intense energy and raw materials required to produce it. In addition, 8% of planet-warming carbon dioxide emission comes from cement production [2]. Good quality aggregates sources are becoming scarce because of the large demand in the concrete construction industry [1]. Due to the global warming and deficiency of good quality local raw materials for concrete, the sustainability of concrete become a subject of interest. The sustainability of concrete can be improved by making it more environmentally friendly. To do that, researchers have been trying to develop approaches to modify the concrete design to produce concrete that is more sustainable. Concrete producers have been looking towards methods to design concrete that is economical [3, 4, 5]. It is globally common practice to use the ACI-211 mix design method to design concrete mixtures. Then, researchers had developed alternative method to optimize the aggregate gradations to optimize the concrete design to improve its durability and sustainability. For example Power 45 chart, Shellstone chart, and 8-18 chart are broadly used to proportion aggregates. However, research has shown that these methods lacks the insights in providing accurate guidance to ensure concrete performance in the fresh state and the hardened state. Then, recently the Tarantula Curve was developed and it has shown great success in producing concrete with good workability, durability and sustainability. In addition, lower cost.

Problem Statement

Recently in Saudi Arabia, a new initiative toward the sustainability has taken place in accordance with the Saudi Arabia Vision 2030. Concrete industry in Saudi Arabia is very huge as most of construction in Saudi Arabia is made of concrete or has concrete [18]. Thus, optimizing concrete mixture design is highly requested to be in line with sustainability initiative in the Vision 2030. The Tarantula Curve has shown great success in improving the concrete sustainability by reducing the cement content and still produce concrete that is workable, durable, and strong. The aim of this research is to design concrete mixtures using the Tarantula Curve and test its boundaries to investigate whether these boundaries apply to the aggregates in Saudi Arabia. Also, comparing mixtures made with the ACI-211 design method and the Tarantula Curve in terms of workability, compressive strength, and cost.

Methodology

Materials were brought to the lab as shown in Table 1

The test used in this project

- Sieve analysis (ASTM C136-137)
- Slump test (ASTM C 143)
- Compressive Strength (ASTM C 39

The cost analysis was done based on the current prices of concrete ingredient in Saudi Arabia.

Materials ID	Specific Gravity	Absorption %	Location
Coarse aggregates			
RUH 20 mm	2.608	1.86	Rumah (Riyadh)
RUH 10 mm	2.606	2.05	Rumah (Riyadh)
Jed 20 mm	2.74	0.82	Jeddah
Jed 10 mm	2.75	0.73	Jeddah
Fine aggregates			
Jeddah sand (JS)	2.81	1.33	(Jeddah)
Dune Sand (D.S)	2.61	0.62	Sulay (Riyadh)
Coarse sand SRCC (C.S)	2.613	1.11	Sulay (Riyadh)
White Sand (W.S)	2.72	0.96	Rumah (Riyadh)
Red Sand (R.S)	2.51	0.58	Rumah (Riyadh)
Alkharj Sand (A.S)	2.70	1.00	Alkharj (Riyadh)
North west Sand (NW.S)	2.60	1.09%	Western (Riyadh)

Table 1

Methodology

Materials were brought to the lab as listed in Table 1

The test used in this project

- Sieve analysis (ASTM C136-137)
- Slump test (ASTM C 143)
- Compressive Strength (ASTM C 39

The cost analysis was done based on the current prices of concrete ingredient in Saudi Arabia.

To evaluate the Tarantula Curve boundaries using materials from Saudi Arabia, first, concrete mixtures were designed to investigate the effects of exceeding the coarse aggregate sieve limits. Fig. 1 shows concrete mixtures prepared using materials from Jeddah region, concrete mixtures prepared using materials from Riyadh region. Then, another set of mixtures were proportioned to evaluate the effect of exceeding the fine aggregates sieves limits, Shown in Fig.1. These mixtures were prepared from materials brought from Riyadh region. All the mixtures were designed with a water-to-cementitious materials ratio (w/cm) of 0.45 and a fixed paste volume with 6 cement sacks to allow the comparison between the workability and compressive strength of various combined gradations

Since it is common to design concrete mixtures in Saudi Arabia using the ACI-211, a comparison between concrete mixtures designed by the ACI-211 method and the Tarantula Curve method was made in terms of workability, compressive strength, and cost as shown in Table 2. The mixtures were designed with a w/cm ratio of 0.45 and the WR dosages were added incrementally as needed to reach a slump between 100 mm- 200 mm with a maximum dosage of 1.68 L/m³.

Results and Discussion

In Saudi Arabia, the sand is available everywhere in enormous amounts. However, most of it is either too fine to use for concrete or too coarse. Finding good quality sand with a good gradation is very challenging. Thus, concrete producers tend to combine coarse sand with fine sand to achieve acceptable sand gradations and meet the ASTM C33 limits. They are using trial and error batches to determine the best combination for each stockpile and every time the aggregate is changed, more trails should be conducted. The Tarantula Curve offers optimized gradations by providing boundaries for sieve size in which when they are exceeded, it tells you about its impact on the mixture. Also, it provides criteria for fine sand and coarse sand as mentioned earlier.

Testing coarse aggregate boundaries

Three mixtures were designed to evaluate the effects of exceeding the coarse aggregates boundaries. The first mixture was designed to exceed the sieve size 12.5mm (1/2") and the second mix was designed to satisfy the limits whereas the third mix was designed to exceed the sieve size 4.75mm (#4) limit. The results of these mixtures are Tabulated in Table 3. It can be noticed that even though the slump results are the highest in **Mix I** and **Mix IV** where it exceeded the limit of the sieve size 12.5 mm (1/2"), the mixture was observed to have high segregation. Fig. 2 shows the segregation occurred in MIX I.

For Mix III and Mix VI, where the sieve size 4.75 mm (#4) was exceeded, harsher mixtures were obtained with some segregation. These results and observations were made with materials obtained from Saudi Arabia. They match the findings in Ghazal et all where when the coarse aggregate boundaries were exceeded, segregation occur in the mixtures [16]. Regarding the compressive strength, it can be noticed that the compressive strength decreased when the combined aggregate gradation goes above the coarse aggregate limits specified by the Tarantula Curve. This is true for both the 7-day and 28-day compressive strength. It is found that these boundaries not only ensure the workability of concrete, but it also ensure the compressive strength of concrete.

Testing fine aggregate boundaries

It can be seen from Table 3 that the slump values of MIX VII and MIX VIII have the same slump value. However, the performance in the compressive strength is higher in MIX VIII than MIX VII where the limits were satisfied in both 7-days and 28-days. MIX IX where the sieve size 2.36 mm (#8) was exceeded showed lower slump value as well as lower compressive strength results in comparison to MIX VIII where the limits were satisfied. This suggests that exceeding boundaries in the Tarantula Curve would not only lower the concrete workability [8], but also, lower the concrete compressive strength in both 7-days and 28-days. The Tarantula Curve boundaries was proved to provide insight about the concrete workability [8, 15,16, 17], but also can provide insight about the compressive strength as well. For the sieve size 0.3 mm (#50), Cook et all found that exceeding the limit for this sieve did not change much in workability and the mixture with high materials retained on this sieve exhibit very smooth surface finish [8]. MIX X and MIX XI in Table 3 showed very similar performance even though MIX XI exceeded the suggested limits in terms of workability. This matches the findings found in Cook et all research. To support their similarity in workability performance, the compressive strength in both mixtures is almost the same.

Comparing the Tarantula Curve to the ACI 211 method

Optimizing aggregate gradation not only helps with the workability behavior and producing cohesive mixtures, but it also helps in saving cement by reducing the paste required to achieve acceptable workability. Several mixtures with different gradations and fine aggregate sources were designed by the ACI-211 method and the Tarantula Curve method and their results are shown in Table 4 Based on the slump data and observation, it can be noted that the ACI-211 mixtures have higher slump values, (design range was 150 mm – 200 mm), these mixes did not require any water-reducing admixtures due to the high paste content. The cement content used in the ACI-211 mixture was 9 sacks. However, the Tarantula Curve required cement content of 6 sacks and the use of mid-range-water-reducing admixture to achieve flowable concrete. In general segregation was observed when designing the concrete mixtures by the ACI-211 method, an example is shown in Fig.3. This is due to the poor gradations of the individual sand sources and the FM. cannot detect which sieve might cause the issue.

Regarding to the compressive strength comparison between the two mix design methods, based on Table 4, the Tarantula Curve provided mixtures with higher compressive strength, about 35%, in comparison to the mixtures from the ACI-211 in both the 7-day and 28-day testing periods. Keep in mind that the Tarantula Curve mixtures had only 6 sacks of cement as opposed to the ACI-211 mixtures, which had 9 sacks of cement.

Cost analysis

To determine the economical perspective of designing concrete mixture by using the Tarantula Curve and the ACI-211 methods, Table 2 shows the cost of each mixture designed by the mentioned methods per cubic meters. It can be observed that the Tarantula Curve mixtures have lower cost in comparison to the ACI-211 mixtures. A concrete producer can save approximately 6.0 % of concrete cost by using the Tarantula Curve method (18 SAR/m³). Optimizing the aggregate gradations in the Tarantula Curve mixtures helped decrease the cementitious materials content and thus the cost.

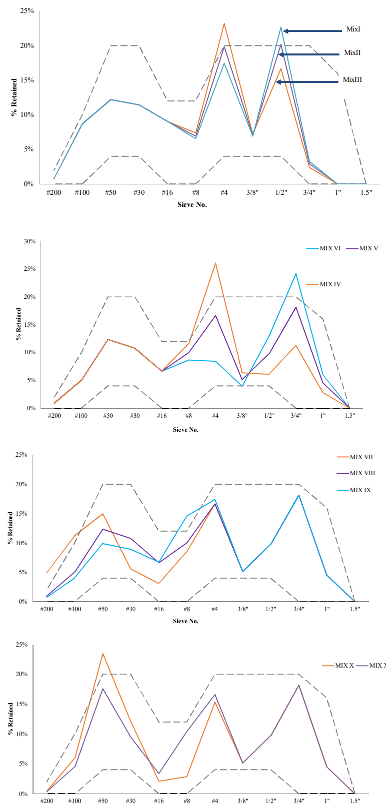

Figure 1

Figure 2

Figure 3

Material	TC1		ACI1		TC2		ACI2		TC3		ACI3		TC4		ACI4		TC5		ACI5	
	weight (kg)	Cost SAR	weight (kg)	Cost SAR	weight (kg)	Cost	weight (kg)	cost	weight (kg)	Cost	weight (kg)	Cost	weight (kg)	cost	weight (kg)	cost	weight (kg)	cost	weight (kg)	cost
Cement 0.279 sr/kg	268	74	364	101	268	74	364	101	268	74	364	101	268	74	364	101	268	74	364	101
Fly ash 0.15. sr/kg	67	10	91	13	67	10	91	13	67	10	91	13	67	10	91	13	67	10	91	13
Water 0.1 sr/kg	151	15	205	20	151	15	205	20	151	15	205	20	151	15	205	20	151	15	205	20
20 mm CA 0.107. sr/kg	486	52	637	68	486	52	609	65	498	53	637	68	498	53	618	66	498	53	633	68
10 mm CA. 0.107. sr/kg	522	56	343	37	522	55	327	34	534	57	343	36	534	57	333	35	534	57	364	39
DS. 0.0982. sr/kg	463	45	439	43	—	—	—	—	305	30	447	43	—	—	—	—	—	—	—	—
CS. 0.112 sr/kg	358	40	226	25	148	16	257	28	—	—	—	—	—	—	—	—	207	23	167	19
RS. 0.1 sr/kg	—		—		638	63	438	43	—	—	—	—	291	29	210	21	—	—	—	—
NW.W 0.1sr/kg	—		—		—	—	—	—	—	—	—	—	—	—	—	—	625	62	526	52
WS. 0.1sr/kg	—		—		—		—		486	48	210	21	486	48	447	44	—	—	—	—
WR. 0.1875sr/kg	1.68		0	0	1.68	0.32	0	0	1.68	0.31	0	0	1.68	0.31	0	0	1.68	0.3	1.68	0
Total cost		292		307		288		313		289		305		288		303		294		312
Difference	15				25				16				15				18			

Mixture	Slump (mm)	Compressive strength (Mpa)	
		7 days	28 days
MIX I (12.5mm sieve exceeded)	220	24.3	35.3
MIX II (Within limits)	180	28.0	38.7
MIX III (4.75mm sieve exceeded)	190	25.3	35.4
MIX IV (12.5mm sieve exceeded)	200	21.2	32.0
MIX V (Within limits)	173	26.5	38.0
MIX VI (4.75mm sieve exceeded)	160	24.0	34.8
MIX VII (Out sieve 75 μm, 0.15 mm)	150	29.5	37.09
MIX VIII (Within limits)	150	29.0	--
MIX IX (Out sieve 2.36 mm)	140	23.6	29.72
MIX X (Within limits)	60	22.0	29.9
MIX XI (Out sieve 0.3 mm)	55	21.5	29.7

Sand source	Mix design method	Slump (mm)	Compressive strength (MPA)		Comments
			7-day	28-day	
DS + CS	ACI-211	190	20	29	Good mix
	Tarantula Curve	140	27	38	Good mix
RS + CS	ACI-211	270	13	20	High segregation
	Tarantula Curve	160	26	32	Good mix
DS + WS	ACI-211	240	17	25	Slight segregation
	Tarantula Curve	235	21	31	Good mix
RS + WS	ACI-211	240	17	24	Slight segregation
	Tarantula Curve	170	24	31	Good mix
NW.S + CS	ACI-211	135	26	--	Good mix
	Tarantula Curve	130	28	--	Good mix

Conclusion

Concrete durability and sustainability can be achieved by optimizing aggregate gradations. This optimization process can reduce the cementitious materials required to produce concrete that is still workable and strong. A recently developed method for combined aggregate gradation was used in this project to verify most critical boundaries using local materials in Saudi Arabia and to determine whether this method is compatible with the use of local materials or not. In addition, a comparison between the Tarantula Curve and the ACI 211 method was made. The following conclusions were drawn:

Exceeding coarse aggregates boundaries provided by the Tarantula Curve produced mixtures with segregation and poor workability.

When exceeding the coarse aggregate sieve limits in the Tarantula Curve, lower compressive strength was obtained. Similar trend occurred in the fine aggregate sieve limits.

The sieves limits for a combined aggregate gradation in the Tarantula Curve not only ensure the workability performance, they also, ensure the compressive strength performance of concrete.

Segregation was observed when designing with the ACI 211 method as a result of the type and quality of the sand available in Saudi Arabia. Mixture design would require many trail and error batches to achieve the acceptable design.

The Tarantula Curve method produced mixtures with compressive strength 35% higher than the ACI 211 mixtures.

ACI 211 mis design method required approximately 9 sacks of cementitious materials whereas the Tarantula Curve required only 6 sacks to produce mixtures with good performance.

The concrete mixtures made with the Tarantula Curve method cost 6% less than the mixtures made with the ACI 211 method.