Performance of Metakaolin Concrete

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Abstract:

The current environmental challenges and studies have been focusing on innovative sustainable materials that can contribute to good quality concrete. Recently, there has been a growing interest in investigating the use of high-reactivity Metakaolin (MK) as a supplementary cementitious material in concrete. Metakaolin is an ultrafine pozzolanic material produced by calcinating purified kaolinite clay at temperatures ranging from 700 to 900°C and is incorporated as a mineral admixture.

This study focuses on studying the performance of concrete incorporating two types of Metakaolin. Thirteen mixtures were prepared using Type I and Type II Metakaolin and different w/c ratios. Metakaolin was added at dosages of 10, 15 and 25% as replacement of Portland cement. In addition, comparative mixtures were prepared using naturally-formed kaolin. The testing program included slump, air content, compressive strength, flexure strength, rapid chloride permeability tests as well as assessment of bonding, chemical attack and corrosion.

Results reveal that Metakaolin-modified mixtures exhibited higher workability as well as improved compressive and flexure strength when compared to conventional mixtures. Furthermore, both Metakaolin and kaolin mixtures have demonstrated less permeability; improved bond strength and enhanced corrosion resistance. Further work is recommended to validate the findings of this study and to pinpoint other potential merits of Metakaolin.

1. INTRODUCTION

Cement production industry is one of the major energy consuming and environmentally polluting industries worldwide because of its great amount of greenhouse gas emissions (green buildings, 2010). In order to reduce energy consumption and increase production, cement plants produce blended cements, comprised of supplementary cementitious materials (SCMs) such as silica fume, natural pozzolanic, fly ash and limestone. The utilization of such materials is environmentally friendly and advocated by many sustainable concrete associations and governments worldwide (Lothenbach et al., 2011; Elahi et al., 2010).

SCMs such as slag, fly ash, husk ash and silica fume has been advocated in the manufacture of concrete due to their improvement performance effect. They generally tend to enhance the mixture's durability and strength (Boddy et al., 2000). The incorporation of SCMs with low water-cement ratio while using great dosages of super plasticizers and water reducers has further proven to effectively enhance the microstructure over that of conventional concrete (Larbi, 1993). Moreover, SCMs particles acquire high surface area, which consume part of the mixing water to get their surface wet, resulting in reducing the amount of free water left in the mixture. In addition to that, the SCMs improve the concrete microstructure by means of either filler effect and/or chemical effect in the form of pozzolanic reaction (Mehta, 1981). Additionally, the pozzolanic reaction produces more calcium silicate hydrate gel, which effectively ties together the hydration products and the un-hydrated cement particles leading to a more homogeneous and denser matrix that reduces permeability (Hadjsadok et al., 2012).

Conversely, there has been a growing interest in the utilization of high-reactivity Metakaolin as a supplementary cementitious material in concrete industry. Metakaolin is an ultrafine pozzolanic material produced by calcinating purified kaolinite clay at a temperature ranging from 700 to 900°C. Such high temperature drives off the chemically bound water and destroys the crystalline structure and inert property (Ambroise et al., 1985). Unlike industrial by-products such as fly ash, silica fume, and blast-furnace slag, Metakaolin is refined carefully to lighten its color, remove its inert impurity and control particle size. The particle size of Metakaolin is generally less than 2 lm, which is significantly smaller than that of cement particles (Ding et al., 2002; Brooks and MegatJohari, 2001). Furthermore, scientists assure that Metakaolin could have very promising influence on concrete performance including and not limited to workability, durability, strength, bonding, resistance to cracks and permeability (Mohammadi, et al., 2014; Shekarchi, et al.,2010; Siddique & Klaus, 2009; Sabir et al.,2001).

The primary focus of this research is to investigate the effectiveness of using two types of Metakaolin incorporated concrete at various replacement levels (10%, 15% and 25%), and assess their performance. The performance of the concretes will be tested in terms of compressive strength, flexure strength, rapid chloride test, bonding test and corrosion test. All samples were tested at different ages up to 28 days for above characteristics.

2. EXPERMENTAL PROGRAM

The experimental program in this study is designed mainly to investigate various properties of different Portland Cement Concrete (PCC) mixtures with two types of Metakaolin; one commercially available and the second self- prepared in the laboratory facilities in the American university in Cairo.

2.1 Materials Properties

The following materials were used for the samples preparations
Cement: Ordinary Portland cement, with specific gravity of 2.65 and specific surface area of 380 m^2/kg.
Water: Municipal tap water for all processes as curing, mixing and cleaning.
Mineral Admixtures: two types of mineral admixtures were used:

1. Commercially available Metakaolin as mineral additive.
2. Self-prepared Metakaolin with controlled calcination process.

The X-ray diffraction pattern of the self-prepared and commercial Metakaolin used in this study is shown in Table 1

Table 1: X-Ray Diffraction Results of self-prepared Metakaolin

Compound (%)	Self-Prepared (%)	Commercial (%)
SiO_2	54	48
Al_2O_3	40	37
Fe_2O_3	2.3	5.2
CaO	0.8	1.4
SO_3	0.9	3.2
Na_2O	0.2	0.8
K_2O	1.1	3.4
Alkaline	0.7	2

Chemical Admixtures: High range water reducer admixture (Sikament Type NN) was used in order to increase the workability of the mixtures at low w/c ratio.
Steel Reinforcement: For the corrosion and bonding tests, 10mm steel bars were used.

2.2 Specimens Preparation

For this study, 13 concrete combinational mixtures were prepared as illustrated in Figure 1. The concrete mixtures were classified into conventional concrete mixtures and three other sets based on the cement replacements which are commercial Metakaolin, self-prepared Metakaolin and kaolin. For the Metakaolin set of mixtures, different proportions of Metakaolin were used (10%, 15% and 25%). Moreover, the kaolin set of mixtures had different proportions of kaolin (10% and 25%). Finally, there were two mixtures of both types of Metakaolin (10%) incorporated without the use of any super plasticizers (SP) admixture.

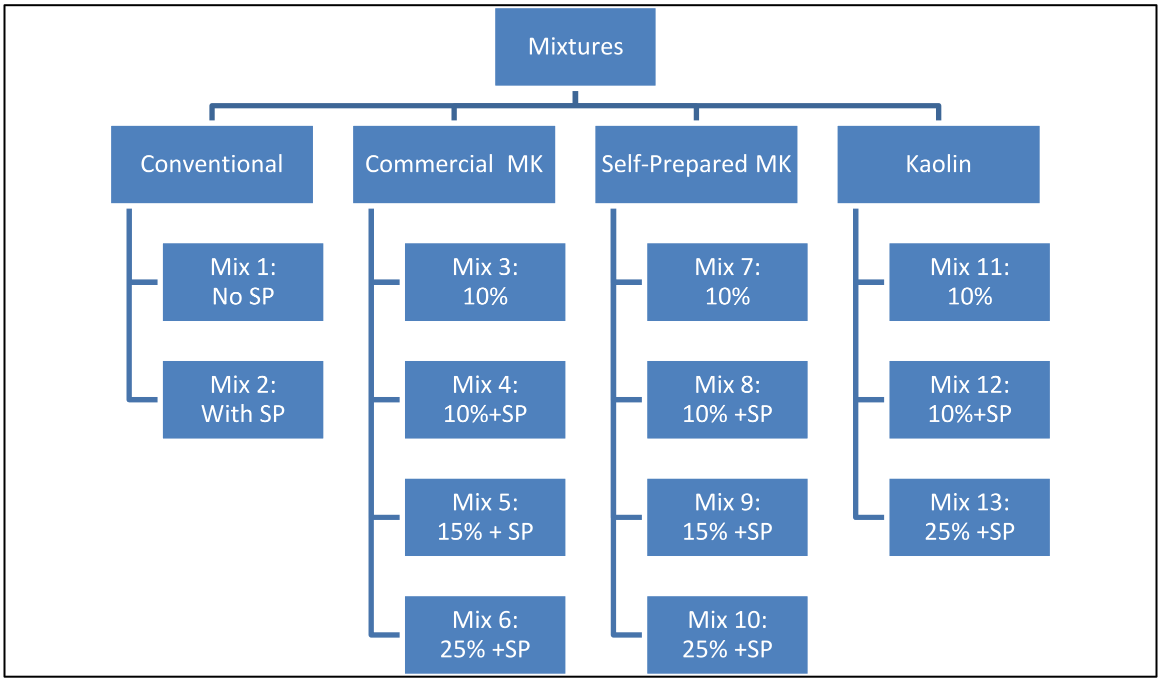


Figure 1: Specimens Preparation

2.3 Concrete Mixtures Design

The concrete mixtures design that was used in this study is shown in Table 2. The water to cement ratio is fixed at 0.4 and the super plasticizer (SP) amount used was 5 liters. The cement quantities were fixed for the conventional concrete mixtures and were varied for the other mixtures by replacing the quantity with the cement replacements (Metakaolin and Kaolin).

Table 2: Concrete Mixture Design

Mix	Cement Replacement Kg	Cement Kg/m³	Water Kg/m³	Fine Agg. Kg/m³	Coarse Agg. Kg/m³	SP Liters	w/c
0%	---	420	185	618	1110	5	0.40
10%	42	378	185	616	1108	5	0.40
15%	63	357	185	614	1106	5	0.40
25%	105	315	185	612	1102	5	0.40

2.4 Test Procedure

The following tests were conducted to examine the PCC mixtures:
Slump Test: according to ASTM C143.

Compressive strength Test: according to BS 1881 on cube specimens 150 x 150 x 150 mm at 3, 7 and 28 days.

Flexural strength Test: according to ASTM C293 using three point bending beams 150 x 150 x 750 mm at 7 and 28 days.
Bonding Test: conducted on 150 x 300 mm cylinder specimens with a 10 mm steel bar embedded in the concrete block. The test was conducted at 7th day.
Corrosion Test: conducted on beam specimens 150 x 150 x 750 mm at 7th day.
Chemical attack Test: conducted on cube specimens 50 x 50 x 50 mm at 28-days. Mixtures were subjected to sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) solutions and the weight loss was calculated.
Rapid Chloride Test: was conducted according to ASTM C1202 on cylinder specimens 30 x 15cm at 28-days.

3. RESULTS AND DISCUSSION

3.1 Slump Test

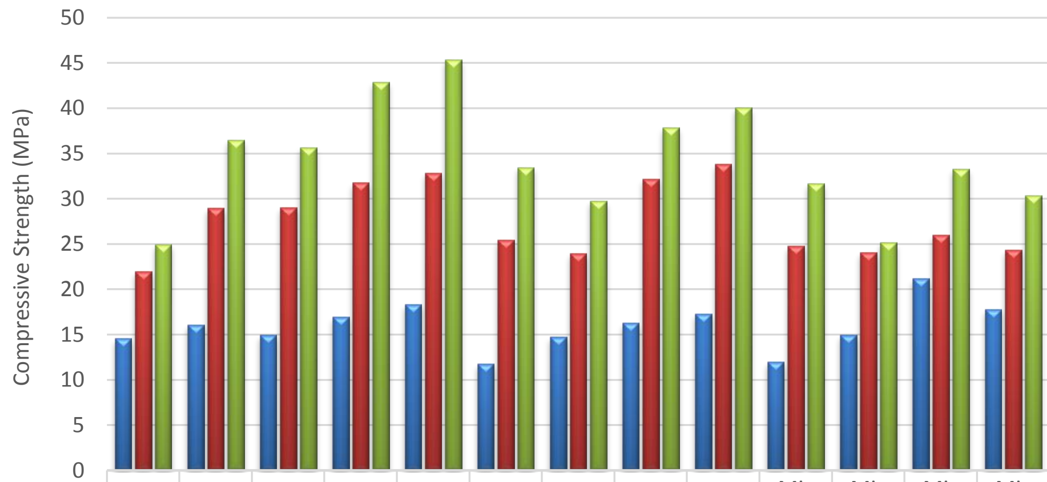
The slump test results are shown in Table 3, and demonstrates better workability for the self-prepared and commercial Metakaolin mixtures than the conventional concrete mixtures. This is mainly due to the addition of the super plasticizer in such Metakaolin mixtures.

Table 3: Slump Test Results

Type	Mixtures	Slump (cm)
Conventional	Mix 1	5
	Mix 2	7
Self-Prepared Metakaolin	Mix 3	16
	Mix 4	14
	Mix 5	15
	Mix 6	15.5
Commercial Metakaolin	Mix 7	10.5
	Mix 8	11.5
	Mix 9	11
	Mix 10	10

3.2 Compressive Strength

Regarding the compressive strength results, the trends of the mixtures are shown in Figure 2, including the 3, 7 and 28 days. Commercial and self-prepared Metakaolin mixtures gave higher compressive strength results than the conventional concrete for percentages of 10 and 15. However, for the 25% mixtures, the strength was not improved. As for the Kaolin mixtures, the compressive strength has not revealed better performance than that of conventional concrete.



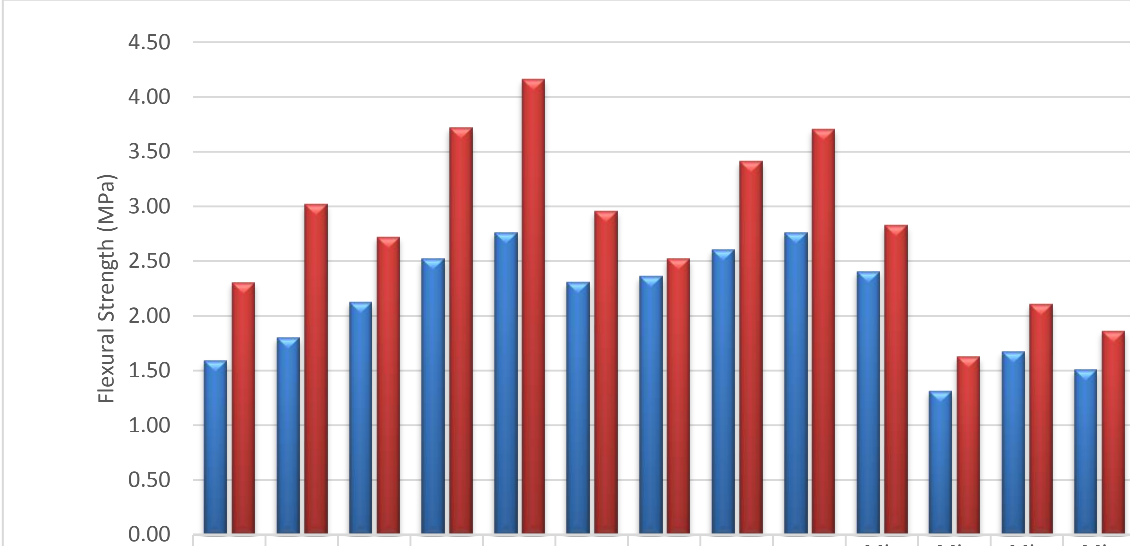
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
3 DAYS	14.6	16.1	15	17	18.4	11.8	14.8	16.3	17.3	12	15	21.2	17.8
7 DAYS	22	29	29.1	31.8	32.9	25.5	24	32.2	33.9	24.8	24.1	26	24.4
28 DAYS	25	36.5	35.7	42.9	45.4	33.5	29.8	37.9	40.1	31.7	25.2	33.3	30.4

Figure 2: Results of Compressive Strength Tests

3.3 Flexure Strength

Figure 3 shows the sample failure due to flexural load. The 7-days and 28-days flexural strengths results are all shown in Figure 4. The results also support the trend of the previous compressive strength test results. The mixtures with commercial and self-prepared Metakaolin gave higher flexural strengths than the conventional concrete mixture, while the Kaolin mixtures gave lower results.

Figure 3: Beam under Flexural Load

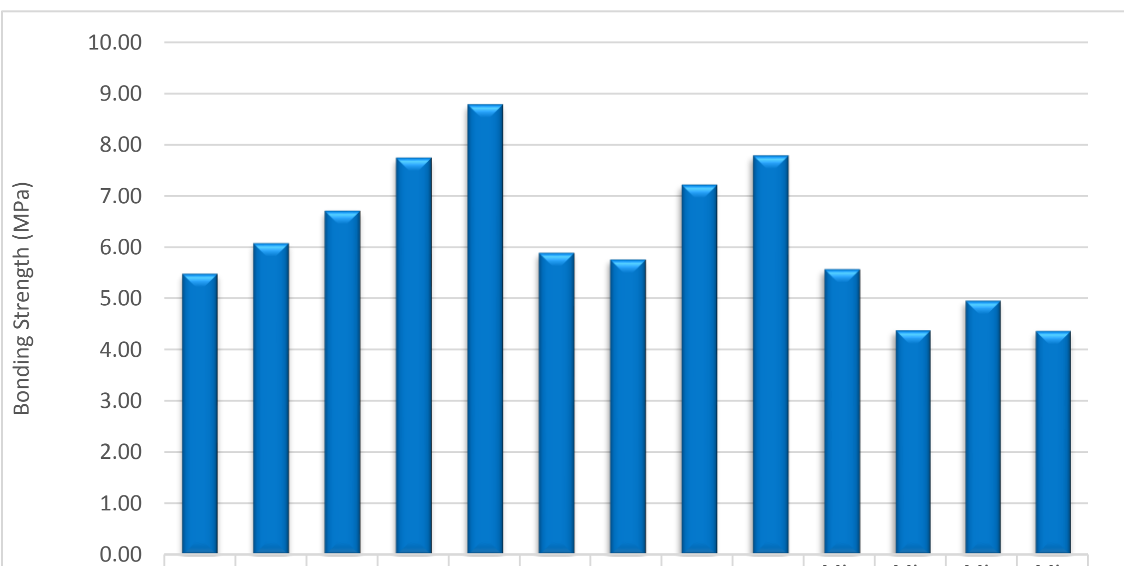


	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
7 DAYS	1.59	1.80	2.13	2.52	2.76	2.31	2.36	2.61	2.77	2.41	1.32	1.67	1.51
28 DAYS	2.31	3.02	2.72	3.72	4.17	2.96	2.53	3.42	3.71	2.83	1.63	2.11	1.86

Figure 4: Results of Flexure Strength

3.4 Bonding Test

Figure 5 shows the results for the bonding test. It reveals that concrete mixtures with Metakaolin have higher bonding strength characteristics until reaching the 15% replacement. However, at 25% replacement, there was drastic drop in the bond strength. Self-prepared Metakaolin gave higher results than commercial Metakaolin which could be due to the higher reactivity of the material. On the other hand, concrete mixtures with kaolin gave the same performance and exhibited lower bonding strength than the conventional concrete.



	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
BONDING	5.50	6.09	6.72	7.75	8.79	5.90	5.77	7.23	7.80	5.58	4.39	4.97	4.38

Figure 5: Results of Bonding Test

3.5 Corrosion Test

All mixtures were tested for corrosion resistance properties. Figure 6 shows the amount of current that passed through the 13 mixtures after 14 days. For corrosion test, the lower the current passed, the less likely the material would experience corrosion and the slower the material loss rate. From Figure 6, corrosion test results showed a decrease in the amount of current passing through the Metakaolin & kaolin mixtures. This could be interpreted as less permeability. This trend is also consistent with the results of the rapid chloride test.

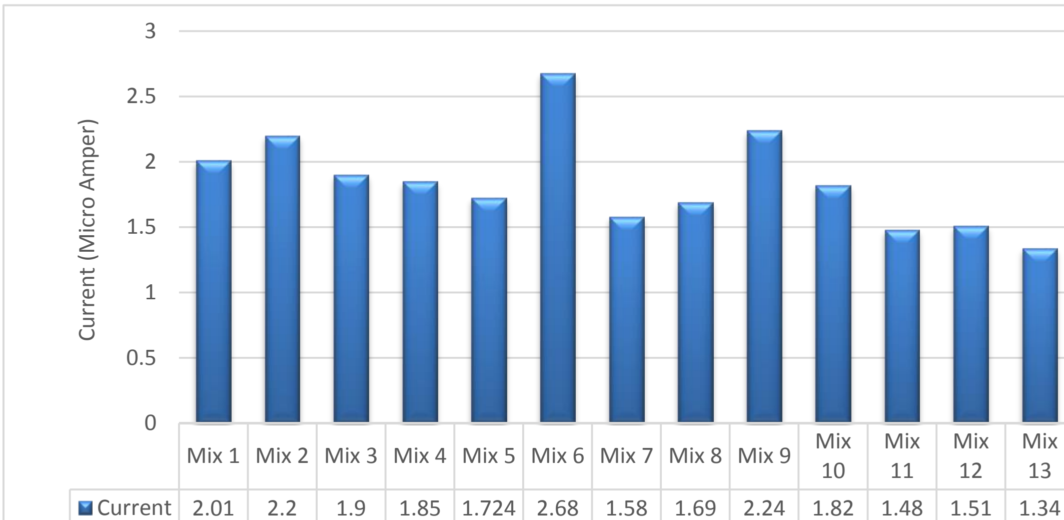


Figure 6 Results of Corrosion Test

3.6 Chemical Attack Test

Figure 7 shows the results of chemical attack test. Notice that the mixtures were affected more by the sulfuric acid than the sodium hydroxide. The self-prepared Metakaolin, commercial Metakaolin and the Kaolin mixtures have shown more or less the same performance of conventional concrete when subjected to chemical compounds with small variations.

3.7 Rapid Chloride Test

Figure 8 shows the results of rapid chloride test. The self-prepared Metakaolin and commercial Metakaolin mixtures have revealed less permeability, and thus better performance than the conventional concrete mixtures. Kaolin had the best results which makes Kaolin a good candidate as a filler due to its low permeability and penetration results

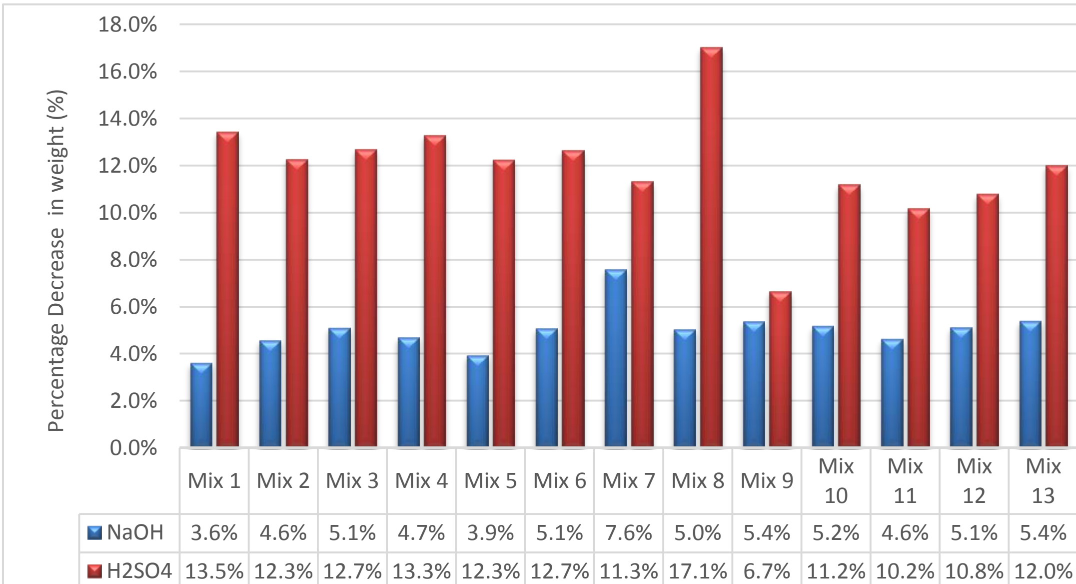


Figure 7 Results of Chemical Attack Test

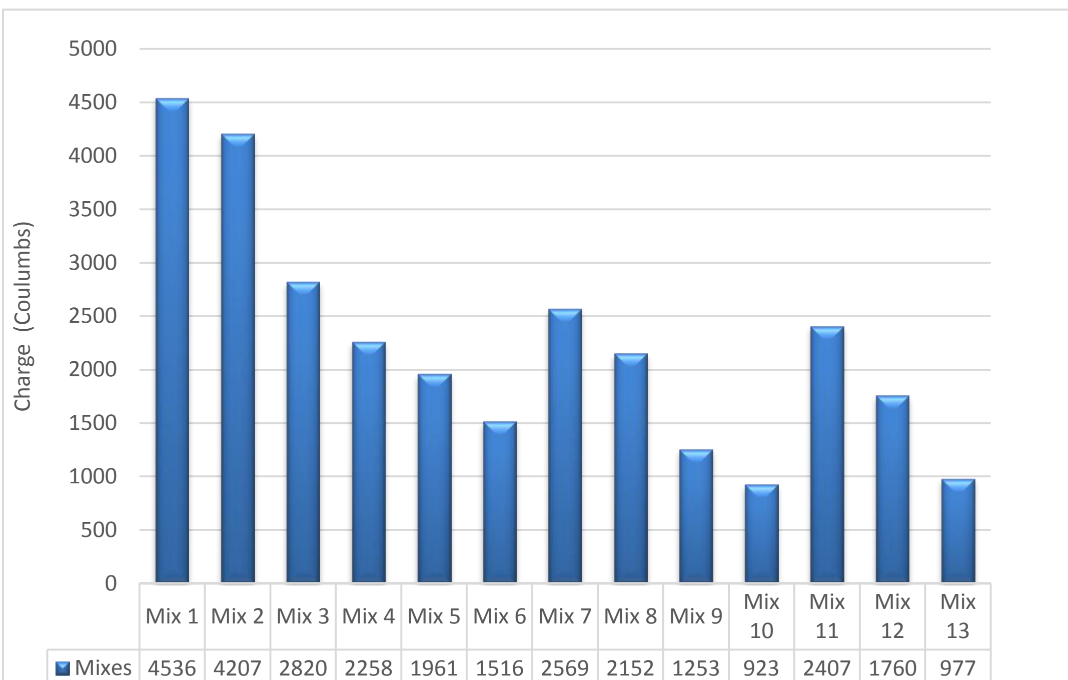


Figure 8: Results of Rapid Chloride Test

4. CONCLUSIONS

Based on all the previous test results, and considering the study's parameters, the following can be concluded:

1. Self-Prepared Metakaolin concrete could be produced by locally available materials in Egypt.
2. Both compressive strength and flexural strength of self-prepared Metakaolin were higher than conventional concrete.
3. The improvement in compressive and flexural strength seems to increase with time as a result of the combined effect of the continuous pozzolanic reaction and the filler effect.
4. Metakaolin mixtures seem to improve durability through a significant reduction in permeability.
5. Kaolin can be used as successful filler due to its very low permeability results.
6. Successful use of Metakaolin can contribute to the environment preservation through reduction of the use of the environmentally-damaging Portland cement as well as incorporation of Metakaolin into concrete industry.
7. Adding Metakaolin as well as kaolin leads to improvement in bond strength and corrosion current.

5. RECOMMENDATIONS AND FUTURE WORK

The following recommendations have been drawn from the previous work:

1. Testing on a wider range of mixtures involving more materials.
2. Conducting further research to study the possibility of utilizing various types of admixtures.
3. Considering a wider range of proportions of coarse to fine aggregates in the mixtures design
4. Considering other w/c ratio's.
5. Examining the behavior of Metakaolin when pouring large-scale structures,
6. Investigating long term properties such as fatigue and creep.

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