Use of Alum and Polyelectrolyte Coagulants in Mixing Water in Concrete Bunkers Building or Construction

● **Dr. Ako Rashed Hama -** Lecturer ●

Komar University of Science and Technology, Civil Engineering Department
University of Sulaimani, Collage of Engineering, Irrigation Engineering Department
ako.rashed@komar.edu.iq

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Abstract

This paper examines the possibility of using water treatment plant's sludge [WTP] in mixing water in preparing high strength concrete bunkers. The two main chemical coagulants used in Dokan WTP 70 km southwest of Sulaimani city in Iraq, are alum and polyelectrolyte and they produce a coagulant's sludge which settled at the end of sedimentation process on the bottom of the clarifier tanks. In this study, the two chemical coagulants alum and polyelectrolyte used as a concrete additives. Samples of the raw water taken from the inlets and have been tested continuously for a time period of 12 months during summer and winter seasons especially at the beginning of the stratification periods of Dokan Lake (source of the treatment plant). The tests included jar tests and turbidity of the samples, then determining the optimum quantity of each of alum and polyelectrolytes. So the maximum amount of the alum was 15mg/L while for polyelectrolyte was 10mg/L. Those two maximum high values of rates of alum and polyelectrolytes and their hybrid mixing rates have been used in preparation 7 concrete prototype bunkers with dimensions of 80cm x 80cm x 15cm with an admixture rates of 15mg/L alum, 15mg/L polyelectrolyte, 10mg/L alum, 10mg/L polyelectrolyte , 10mg/L alum with 5 mg/L polyelectrolyte, 5 mg/L alum with 5 mg/L polyelectrolyte and zero mg/L for both of them (blank). Two different types of tests have been performed for the prepared concrete bunkers; the in-lab compression tests for the cube samples of the prototypes concrete and the outdoor field shouting test for the prepared concrete bunker prototypes using 12.7 mm gun fire bullets and a shooting 100m from the target. Concrete compression laboratory tests have been conducted for 7,21and 28days aged concrete prototype bunkers while the depth, length and the diameter of the cracks and punching of the bullet hitting locations on the targeted prototype concrete bunker were measured. The results of this research reveals that adding alum along either in 15mg/l or 10 mg/ l doses in the three aged concrete 7,21,and 28 days will affect inversly on the concrete compaction strength by a (1 – 8)% while adding the other mensioned doses (polyelectrolyte along with different doses 10mg/l or 15 mg/l and a hybird doses of alum 10mg/l mixed with polyelectrolite 10mg/l ,will help in increasing the concrete compression strength of the concrete by 3.5% to 12%. Through out the tests its clearly appeared that the optimum coagulant in increasing the capacity of the concrete is polyelectrolyte and with a dosage of 15mg/l and it helps to increase the capacity of the concrete to 9% at 7days , 11.5 % at 21days and 13% at 28days from the age of the concrete .The results showed that the penetration depth for all the seven concrete bunker prototypes, evaluates each prototype performance via their penetration depths, because the penetration depth of the bullet is the most important variable in selecting the best performance concrete bunker prototype among all of them. The results also showed that the minimum penetration was 1.7 cm of polyelectrolyte used coagulant prototype of 15mg/L, and the maximum ratio about 2.2cm for the concrete banker prototype containing 15 mg/L of polyelectrolyte coagulant in mixing water of the concrete mixture used in it. Also the smallest diameter as a result of shooting test was 10 cm for this prototype while the largest diameter was 20 cm for the bunker prototype containing 10 mg/L of polyelectrolyte coagulant in mixing water of the mixture used in it.

Keywords: Alum, Polyelectrolyte, Coagulants, water treatment plants Sludge, Concrete Bunkers, compressive strength.

1. Introduction

With the increasing demand for safe and/high-quality treated water, a deferent or chemicals have been used as a coagulants or coagulant aids in water treatment processes that produce a high amount of purified drinking water as well as a high amount of chemically enriched sludge [CES] levels as a wastes.

Dokan water treatment plant [DWTP] located 50 km west of Sulaimani city [35°33′26″N 45°26′08″E] and has a maximum capacity of 12000 m^3/hr .The treatment plant following traditional treating processes of raw water from the intake source with a set of different phases as shown in Fig.1 .In the end of DWTP phases, usually results in chemically enriched sludge[CES]. CES usually contains high doses of used coagulant chemicals like alum and polyelectrolyte figures 2 and 3. CES usually discharged into Qashkoli downstream of Dokan Dam. In this research alum and polyelectrolyte CES were used as a concrete product admixtures for different reasons, one of them is cleaning the environment around the WTP itself, and the second which is the primary objective of this research was enhancing the concrete bunkers capacity against 12.7 mm bullets and /or any falling bombs or other attacks and to protect solders. The used concrete type of the bunkers should be different from other ordinary concrete properties, and also the concrete design process should lead to much harder concrete than the conventional concrete. The reason behind using concrete for bunkers is that; concrete is a powerful hard and high resistance material in terms of compression strength impacts. Concrete is that is of very weak property in tensile strength. For preparing the concrete bunkers prototype models with different mixing design rates and CES admixtures from alum and polyelectrolyte were used to discover the effect of CES on the concrete strength properties. To solve the tensile strength problems of the prepared concrete bunkers prototypes, resisting the moulds of puncturing and getting the bullet through; embedding a double layer chicken wire meshing.

2. Dokan Water Treatment Plant

DWTP was built and constructed in 2009 downstream Dokan Lake Fig.1. DWTP includes: Two flash mixers, eight clarifiers four of them 36 m in diameter and 8 m in high, and the other four are 30 m in diameter and 8 m high, and two chlorination tanks 47.5 m x 34.6 m and depth 4.5 m. The capacity of SWTP is (8000-12000) m^3/h and it is the main source of drinking water for Sulaimani city residents and some other neighbour districts like Chamchamal and Tasluja west of Sulaimani ,Iraq.

3. Literature Review

Usually WTP's produce about 80,000 tons annually of coagulants sludge [CS] wasted as a by-product of purifying water processes for water consumption (Alqam et al.,2011). The sludge generated in WTP's consists of organic and inorganic matters in solid, liquid, and gaseous states, and varies in terms of physical, chemical, and biological characteristics (Bourgeois et al.,2004). The volume of discarded waste depends on the characteristics of the operational units involved and also the quality of the raw water. The frequently used chemical coagulants and coagulant aids in water treatment processes are: aluminum salts (alum) ($Al_2(SO_4)_3 18H_2O$), ferric ion salts (such as $FeCl_3.6H_2O$), and ferrous iron salts (such as $FeCl_2$, $FeSO_4.7H_2O$) (Fytianos et. al.,1998).

The addition of these chemical coagulants during water treatment processes results in an iron or aluminum rich sludge (Zhao,2007). These salts may be present in high concentration that could be toxic to aquatic biota. To avoid this type of toxicity, these salts should be treated prior to their disposal or reuse as a sludge (Guan et al.,2005). Studies were conducted to examine the potential of using sludge and sludge ash in the production of building and construction materials, as well as in brick, artificial aggregate, cement, and ceramics production. Typical examples of the direct use of sludge ash from WTP's are: as filler in concrete (Tay,1987) and as a cementation building material (Tay and Show,1992). Ebeling et al. (2003) and his partners in their research about aqua-cultural engineering evaluated th chemical coagulants in the removal of the water impurities and phosphorus from intensive effluent discharge. Evaluation of the commonly used coagulants alum and ferric chloride was conducted for samples of overflow from the filters in an intensive recirculating aquaculture system using standard jar test procedures. The removal of orthophosphate for alum and ferric chloride can be reached till 89% and 93%, respectively, at a dosage of 90 mg/l with final concentrations of sludge recycling approaching 0.3 mg/l as P (Clesceri et al.,1999). King et al. (1975) studied the recovery and reuse of coagulants from WTPs during March 1975. It was also concluded from their study of alum and iron sludge coagulants recovery from both water and wastewater plants that the feasibility of using the technics that acidic method of alum recovery from water and wastewater alum sludge adapted. Alum recovery process is not difficult and the amount of alum recovered can be calculated from stoichiometry. High level reduction in sludge volume produced for both alum and iron systems due to an increase in acidity. The recovering efficiency of metals in coagulation process is not appreciably lower than that of fresh coagulant(King et al.,1975) . Laskar (2011) founded that in high-performance concrete mixing design research that a proposed mix design procedure takes rheological parameters into account in determining compressive strength, water cement ratio and aggregate volume to paste volume ratio. Always the difficulties to develop a mix design method which can be used universally for the same properties of fresh and hardened concrete can be achieved by different ways from same materials.

4. Prototype Models Properties and Dimensions

In this research a double chicken wires mesh were also used in preparing the concrete model prototypes .Chicken mesh wires are used as barrier in different situation because of their strength and durability which made of thin and flexible steel, also they prevent the formation of internal stresses and improve corrosion resistance. Chicken mesh wires correctly placed for reinforcement plastering in construction because of its mechanical properties of suitability, reinforcement waterproofing, levelling floors and facade work. The diameter of the used mesh wire was 2.0 mm. In concrete mix design, the ratio of cement, sand, and aggregate of 1:1:2 will produce a concrete of compressive strength that will be affected by the amount of cement and aggregate the bigger amount of cement and aggregate effects of more compressive strength furthermore, the ratio of water cement effects on workability and compressive strength which increase the workability and decrease the compressive strength (Alqam et al.,2011).

In this experimental work, seven prototypes has been prepared 80 cm length x 80 cm wide 15cm thickness in dimensions and a volume of 0.096 m^3 for each prototype, and mid layered by double chicken mesh wires.

5. Concrete Admixtures

Admixtures usually are added to concrete before or while mixing concrete. They will be added to improve the quality of concrete, it gives high resistance, workability and strength. In order to have a high strength the prototype must be made in high quality with adding admixtures to be strong enough while bullet shooting. To get this and achieving this goal there are different types of admixture could be add. In our research we used alum and polyelectrolyte as admixtures and may have different results comparing to another types of admixtures.

Alum is a hydrated form of potassium aluminum sulphate and has a chemical formula $KAl(SO_4)_2{\cdot}12H_2O$ also any compounds with the formula of AB $(SO_4)_2{\cdot}12H_2O$ considered to be alum. Alum seen in its crystalline form, although it is most often is a powder, potassium alum is a fine white powder that is used in water purification as a chemical flocculants and polyelectrolytes are polymers that they fall apart in water. Properties of polyelectrolytes are similar to properties of electrolytes and polymers. Polyelectrolytes use in many applications, such as improving the stability of aqueous colloids and gels or to induce agglomeration. They can be used to destabilize a colloidal suspension and to initiate flocculation and precipitation .In DWTP alum and polyelectrolytes used in water treatment processes as coagulant and coagulant aids Figures 2 & 3. It was found that the added doses of the used two coagulants in DWTP by analysing the jar tests results of the raw water turbidity tests data for a period of one year continuously including deferent seasons and various weather conditions. The results showed that a maximum dose of 15 mg/l for each coagulants alum and polyelectrolyte have been used annually .The peak values of the used coagulants, in this research for the amount of alum and polyelectrolyte and their hybrid ratios were used in preparing the concrete prototype models and one without adding any of the used coagulants as a blank model for comparing the results.

6. Reuse of the Sludge of WTPs

Sludge usually generated from chemical precipitation, sedimentation, and other primary processes in the water purification processes at the treatment plants. The sludge is the residue that accumulates in WTP mainly in the last phase of the many processes that occur in the bottom of the treatment plant units. The type and percentage of each of the alum and polyelectrolyte's sludge differs from a plant to plant and a tank to tank due to the difference of waste rate and amount of water that enters the treatment plant. When more water consists to treat it, it means more alum and polyelectrolytes are going to be used in the overall process. Also, when there is more turbid raw water and contaminated water, it means that percentage and the rate of using there coagulants and polymers must be very high to get the pure water. Sludge is a produced from the treatment of water because of a primary aim of water treatment is removing solids from the water. In addition, soluble organic substances are converted to bacterial cells, and the heavy materials are removed from the water. The qualities of sludge varied broadly from fresh mountain water, to rainfall, to water in lakes and ponds and the classification is made from primary and secondary tests of the raw water to determine the time and amount of adding materials for the water to be used for drinking.

7. Results and Discussion

The fire shooting tests performed in reality and field site in shooting land sense area at the training of Peshmarga forces commanders department. The bullets type that have been used in this research for the purposes of real shooting tests were of two types bullet :burner and cutter 12.7 mm as shown in figure 4 and the tests were achieved at 100 m distance from each the target prototype models.

The results of the compression tests for the three aged concrete cubes which was performed according to(ASTM 1991) standards as shown in figures 5 and 6 reveal that adding alum along either in 15 or 10 mg/l doses in the three aged concrete 7,21 and 28 days will affect inversely on the compaction strength by a (1%–8%) while adding the other mentioned doses (polyelectrolyte along with different doses 10 mg/l and 15 mg/l and a hybrid doses of alum 10 mg/l mixed with polyelectrolyte 10 mg/l will help in increasing the compression strength of the concrete from 3.5% to 12% . Throughout the tests, its clearly appeared that the optimum coagulant in increasing the capacity of the concrete is polyelectrolyte and with a dosage of 15mg/l and it helps to increase the capacity of the concrete to 9% at 7 days, 11.5 % at 21 days and 13% at 28 days from the age of the concrete as shown in figures 7 and 8.

Prototype number one which is a concrete with a mix design ratio 1:1:2 is prepared by alum coagulant with a ratio of 15.0 mg/L. As shown in figures 12 the bullet does not have any crack but it has penetration about 2.2 cm with bullet shooting effect maximum diameter 10.5cm and minimum diameter 9.7cm without any crack .Generally this prototype sample is strong enough to use as bunker to protect Peshmarga . The same as prototype number one, Prototype number two which was also prepared in the same dimensions of prototype one , and also alum was added to the concrete mixture of 10.0 mg/l. As it can be seen, in figure 13 the bullet went through the corner of the prototype with penetration 2.3 cm ,maximum destroyed diameter of 12cm ,and minimum destroyed diameter of 7cm without any crack. The added coagulant to of prototype number three as admixture was polyelectrolyte with ratio 15.0 mg/L.As it is shown in figure 14, it has the lowest penetration between all of the prototype samples which is 1.7cm and maximum diameter 11.5cm and minimum diameter 10cm without any crack. This reveals that polyelectrolyte is a good coagulant to be used as an admixture in concrete. Prototype number four was as prototype number three with different polyelectrolyte ratio of 10 mg/l .It was different than all the other prototypes because the bullet went through the corner of the prototype as shown in Figure 15, with a maximum destroyed diameter of 18.0cm and a minimum destroyed diameter of 10.0cm without any crack. For prototype number five , a hybrid mixture of both coagulants alum and polyelectrolyte with their ratios (10.0 and 5.0) mg/L; respectively. The depth of penetration of the sample was 2.3 cm and the maximum destroyed diameter was 12.0cm and the minimum destroyed diameter 10.0cm without any crack.

In the preparing prototype number six, also a hybrid mixture of the both two coagulants alum and polyelectrolyte with 5 mg/L per each of them was used. The penetration depth was 1.9 cm, and the affected maximum diameter 11.8cm and minimum diameter 8.5cm without any crack as shown in Fig.12, which produced the second lowest penetration depth after prototype number three. Prototype number seven which was considered to be blank, which is means that it doesn't contain any coagulants as an admixtures (alum and polyelectrolyte). This sample produced much more penetration depth than the rest of the other prototypes and was 3.3cm with a maximum diameter of 12.0cm and a minimum diameter of 10.0cm without any crack as shown in Fig.13.The minimum destroyed diameter as shown in a bar chart in a figure9 conclude that the result of a shooting test caused the destroying diameter of minimum ratio by the highest ratio of

polyelectrolyte %20 and smallest ratio about %12 of Alum.
The penetration depth ratios for all the seven concrete bunker prototype models shown in the bar chart in figure 10 which evaluates each prototype performance via their penetration depths as the penetration depth of the bullet is the most important variable in selecting the best performance concrete bunker prototype among all of them. The results also showed that the minimum penetration depth was 1.7cm of polyelectrolyte used coagulant prototype of 15 mg/L, and the maximum depth was 2.2cm for alum used coagulant prototype 10 mg/L and alum 10 mg/L +Polyelectrolyte 5 mg/L. The maximum destroyed diameter during the field bullet shooting test as shown in figure11 resulting that the highest ratio of maximum destroyed diameter was 20cm with polyelectrolyte used coagulant prototype of 10 mg/L and the lowest one was 12cm while using alum coagulant as admixture of 15 mg/l dosage.
Table -3 Shows the results of field shooting test

8. Conclusion

It was concluded that added alum by 15 mg/l or 10 mg/ l doses in the three concrete mixtures at 7,21 and 28 days affect negatively on the compressive strength by (1% – 8%) while the other dosage (polyelectrolyte along with different dosages(10mg/l and 15 mg/l) and a hybrid doses of alum 10 mg/l mixed with polyelectrolyte 10mg/l , increase the compressive strength of the concrete by 3.5% to 12% . Its clearly appeared that the optimum coagulant in increasing the strength of the concrete is polyelectrolyte with a dosage of 15mg/l which increase the strength of the concrete to 9% at 7 days , 11.5 % at 21 days and 13% at 28 days. The results also showed that the minimum penetration depth was 1.7cm of polyelectrolyte (15 mg/L), and the maximum depth was 2.2cm for alum (10 mg/L) and (alum 10 mg/L +Polyelectrolyte 5 mg/L). The maximum diameter during the shooting test was 20cm with polyelectrolyte of 10 mg/L and the lowest one was 12cm while using alum of 15 mg/l dosage. The outcome of this study was very acceptable and valuable for designing bunker by using alum and polyelectrolyte in mixing of water for concrete mixtures as prototype number three in which polyelectrolyte added to its mixture in the mixing water by 15 mg/L and prototype number six which was alum and polyelectrolyte with an equal dosage of 5 mg/L each of them had the lowest ratio of penetration.

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إستخدام مخثرات الشب والبولي ألكتروليت في ماء الخلط للخلطات الخرسانية المستخدمة في إنشاء السواتر

د . آكو رشيد حمه – مدرس
جامعة كومار للعلوم والتكنلوجيا – قسم الهندسة المدنية
جامعة السليمانية – كلية الهندسة – قسم هندسة الري

المستخلص

تم في هذه الدراسة إستخدام المياه الفنية بمادتي الشب والبولي ألكتروليت اللتين هما من اكثر المخثرات شائعة الإستخدام في محطات التصفية كمحطة دوكان لتصفة مياه الإسالة والواقعة جنوب شرق مدينة السليمانية اذ تم إستخدامها كماء خلط في الخلطات الخرسانية عالية المقاومة والمستخدمة في إنشاء السواتر الخرسانية اذ تم إستخدام جرعات مختلفة من الشب والبولي ألكتروليت بالإعتماد على القيم القصوى للإستهلاك في المحطة خلال فترة زمنية مقدارها سنة اذ بلغت 15 ملغ/ لتر من الشب و 10 ملغ/لتر من البولي ألكتروليت. تم إنشاء سبعة نماذج من السواتر الخرسانية بأبعاد 80سم x80 سم 15 xسم. كانت نسب الاضافة للمواد المخثرة الكيميائية الى ماء الخلط 10 و 15 ملغ/ لتر من شب لوحدهما ، 10 و 15 ملغ/لتر من البولي ألكتروليت لوحدهما ، و 10 ملغ/لتر من شب مع 5 ملغ/لتر من البولي ألكتروليت معا ، 5 ملغ/لتر من الشب مع 5 ملغ/لتر من البولي ألكتروليت معا وكما تم مقارنة الخلطات الحاوية على هذه النماذج من ماء الخلط مع خلطة مرجعية ذات ماء خلط إعتيادي (غير حاوي على الشب او البولي اليكتوليت) . استخدم نوعان من الفحوصات لغرض معرفة مدى تأثر مقاومة الخرسانة عند إضافة تلك المواد وهما فحص مقاومة الإنضغاط للمكعبات والفحص الموقعي بإستخدام الرمي من رشاش آلي ذو ذخيرة حية بعيار 12.7 ملم من موقع ثابت وعن مسافة ثابتة تبلغ 100م. بينت النتائج بان إستخدام الشب في ماء الخلط تقلل من مقاومة الخرسانة للانضغاط بنسبة تراوحت من 1**%** الى 8**%** في المقابل لوحظ ان إستخدام البولي اليكتوليت بشكل منفرد في ماء الخلط او بشكل مركب مع الشب ادى الى زيادة مقاومة الإنضغاط بنسبة تراوحت من (3.5 الى 13)**%** اذ عند إضافة 15 ملغ/لتر من البولي اليكتروليت الى ماء الخلط ، لوحظ بان نسبة الزيادة في مقاومة الإنضغط بلغت (13، 11.5 و 9)**%** عند الأعمار (7، 21 و 28) يوما على التوالي كما أن نسب الزيادة هذه تمثل النسب الأعلى مقارنة بالبقية الخلطات.أظهرت نتائج ألرمي الحقلي على نماذج السواتر والتي تعتبر دليل آخر لمعرفة مدى تأثر النماذج بالمواد المخثرة الكيميائية المضافة كانت أقل قيمة مقاسة لعمق إختراق الذخيرة في النماذج الخرسانية بلغت 1.7 سم للنموذج التي يحتوي على 15ملغ/لتر من البولي اليكترويت أما أعلى قيمة للعمق كانت 2.2 سم. كما ان أكبر قطر متأثر بالذخيرة كان 18 سم للنموذج الذي يحتوي على 15 ملغ/لتر من البولي أليكتروليت أما أضغرها فقد بلغ 10 سم عند النموذج الذي يحتوى على 15 ملغ/لتر من مادة الشب. بذلك يمكن القول بأن المواد المخثرة الكيمياوية تزيد من مقاومة الإنضغاط للخرسانة المستخدمة في السواتر الخرسانية.

الكلمات المفتاحية : الشب ، البوليئليكترولايت ، السواتر الخرسانية ، التخثير ، اعادة استخدام ، المقاومة الانضغاطية.

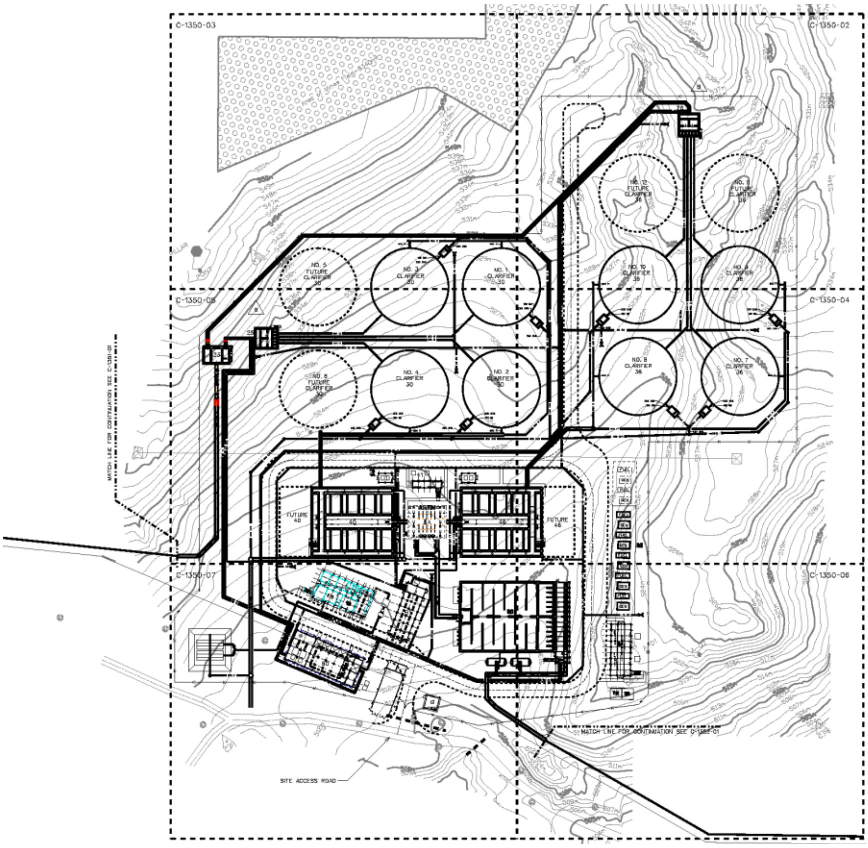


Fig. 1 : Dokan Water Treatment Plant Layout.

Fig. 2 : Used Polyelectrolyte as a coagulant.

Fig. 3 : Used Alum as a coagulant.

Table 1 : The amount of used material in preparing each prototype.

Prototype No.	Cement (kg)	Sand (m^3)	Aggregate (m^3)	Dose of coagulants used as Admixture (mg/l)	
				Alum	Polyelectrolyte
1	200	0.25	0.45	15	0
2	200	0.25	0.45	10	0
3	200	0.25	0.45	0	15
4	200	0.25	0.45	0	10
5	200	0.25	0.45	10	5
6	200	0.25	0.45	5	5
7	200	0.25	0.45	0	0

Fig 4 :12.7mm Bullets which are used in the research.

Table 2 : Mix designs of admixture compression test.

Prototype Number	Mix Designs	Admixtures
1	1:1:2	Alum
2	1:1:2	Alum
3	1:1:2	Polyelectrolyte
4	1:1:2	Polyelectrolyte
5	1:1:2	Alum+Polyelectrolyte
6	1:1:2	Alum+Polyelectrolyte
7	1:1:2	Blank

Fig 5 : Concrete Cubes for compression testing.

Fig 6 : The used lab compression test machine.

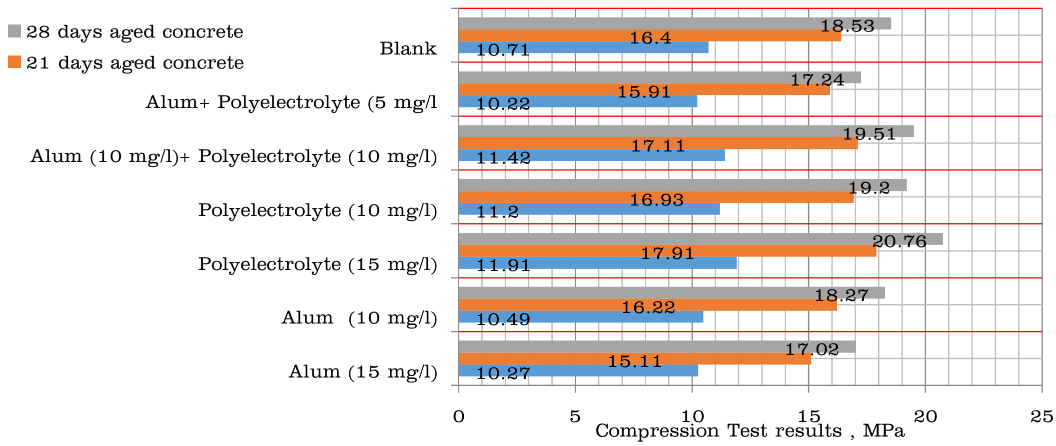


Fig. 7 : In lab compression tests for the samples of 7,21 and 28 days of the concrete.

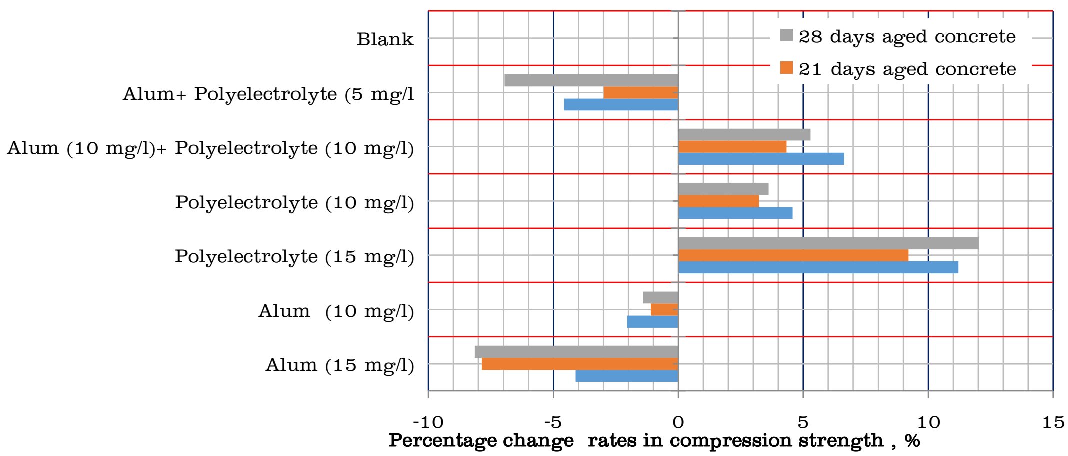


Fig. 8 : Increase /Decrease percentage rates in for the samples of 7,21 and 28 days of the concrete compression strength , with respect to the blanck prototypes.

Table 3 : Shows the results of field shooting test.

Prototype #	Prototype sample admixture used	Maximum Penetration depth (cm)	Maximum destroyed diameter (cm)	Minimum destroyed diameter (cm)
1	Alum (15 mg/l)	2.2	10.5	9.7
2	Alum (10 mg/l)	2.3	12.0	7.0
3	Polyelectrolyte (15 mg/l)	1.7	11.5	10.0
4	Polyelectrolyte (10 mg/l)	NA	18.0	10.0
5	Alum (10 mg/l)+ Polyelectrolyte (10 mg/l)	2.3	12.0	10.0
6	Alum+ Polyelectrolyte (5 mg/l)	1.9	11.8	8.5
7	Blank	3.3	12.0	10.0

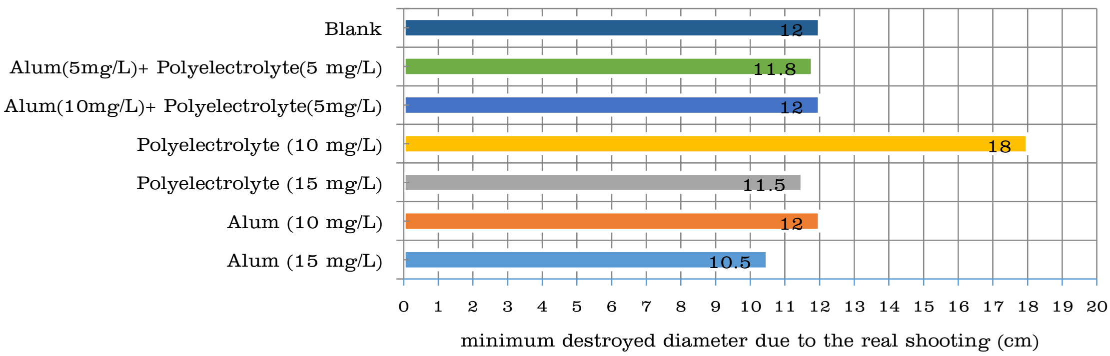


Fig. 9 : Minimum destroyed Diameter for the prototypes with the field bullet shooting test.

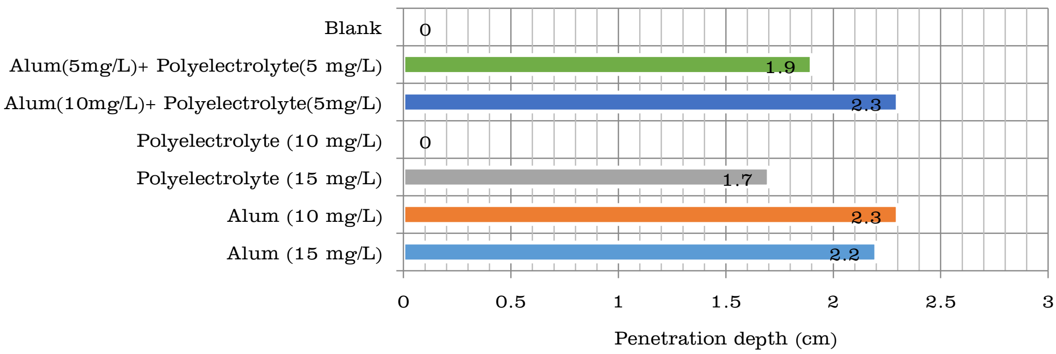


Fig. 10 : Penetration Depth Ratio for the prototypes with the field bullet shooting test.

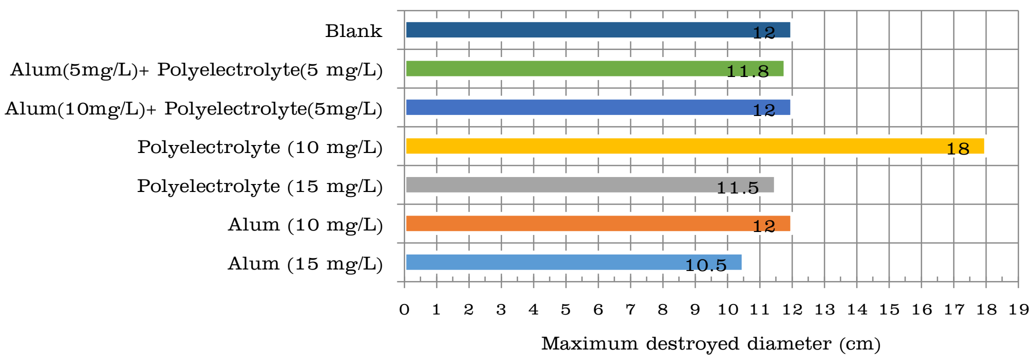


Fig. 11 : Maximum destroyed diameter (cm).

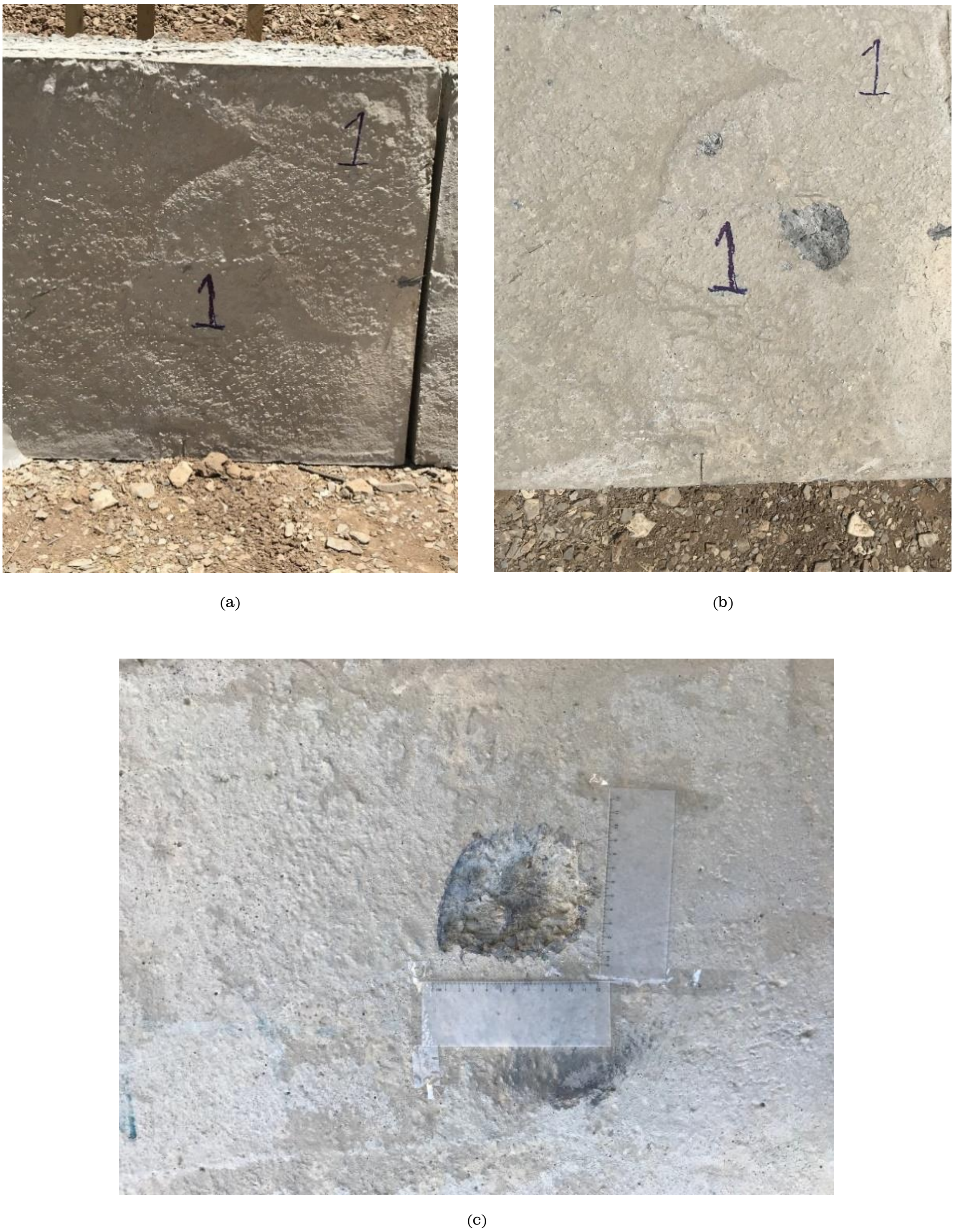
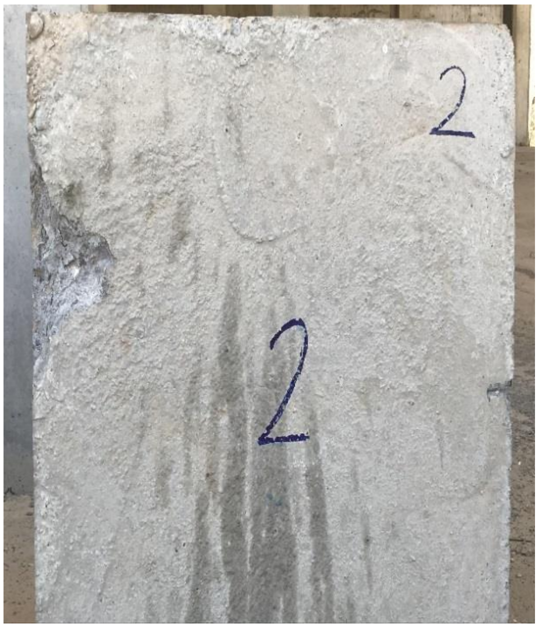
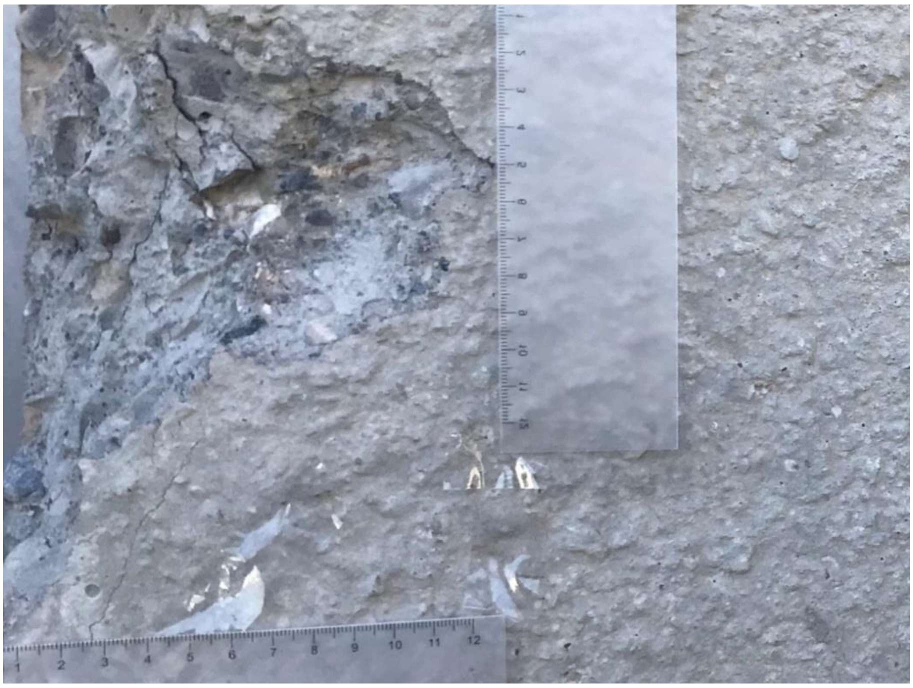


Fig. 12 : Prototype #1 before (left) and after shooting (right) with Alum (15 mg/L).

(a)

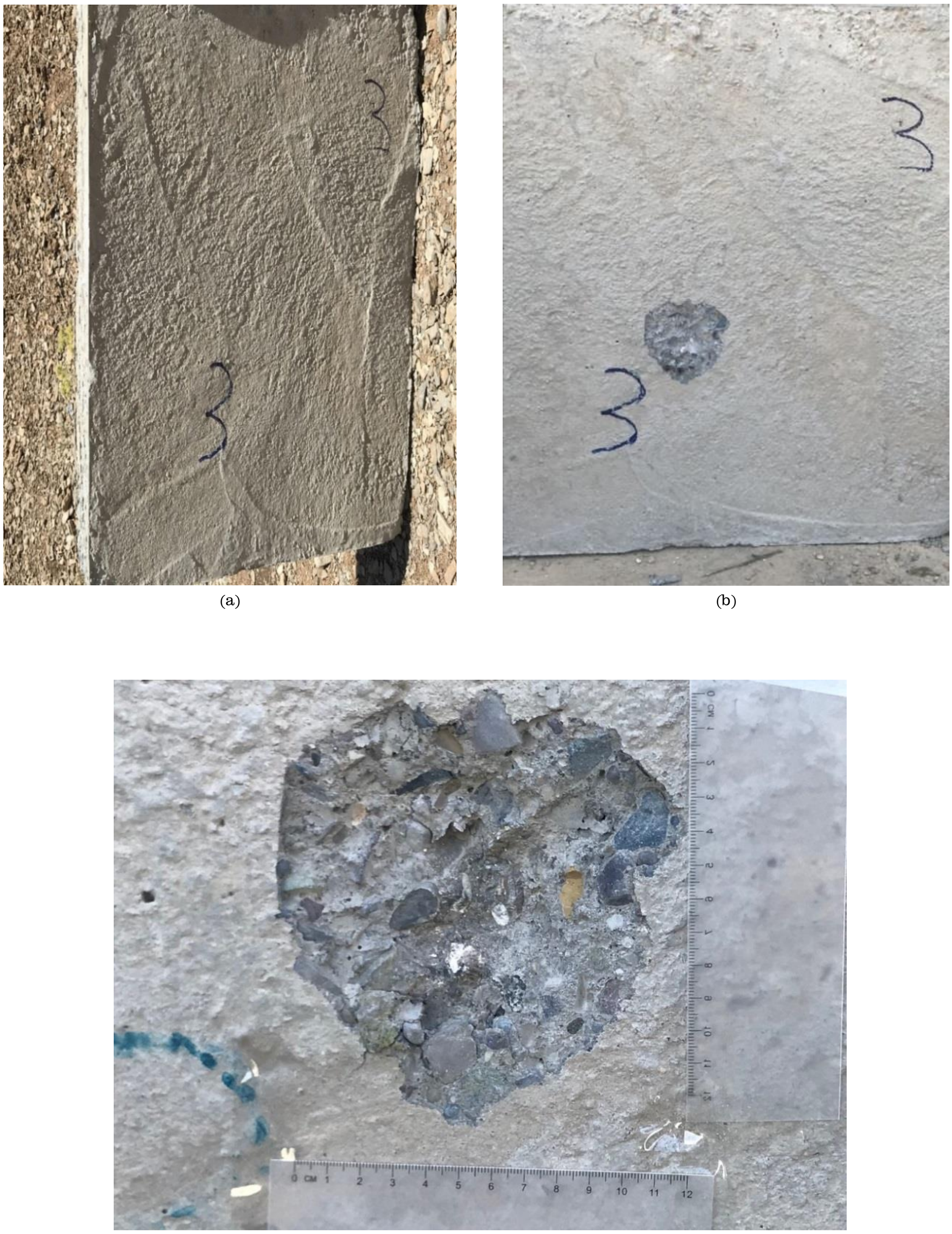


(b)



(c)

Fig. 13 : Prototype #2 before (left) and after shooting (right) with Alum (10 mg/L).



(a) (b)

(c)

Fig. 14 : Prototype #3 before (left) and after shooting (right) with Polyelectrolyte (15 mg/L).

(a)

(b)

(c)

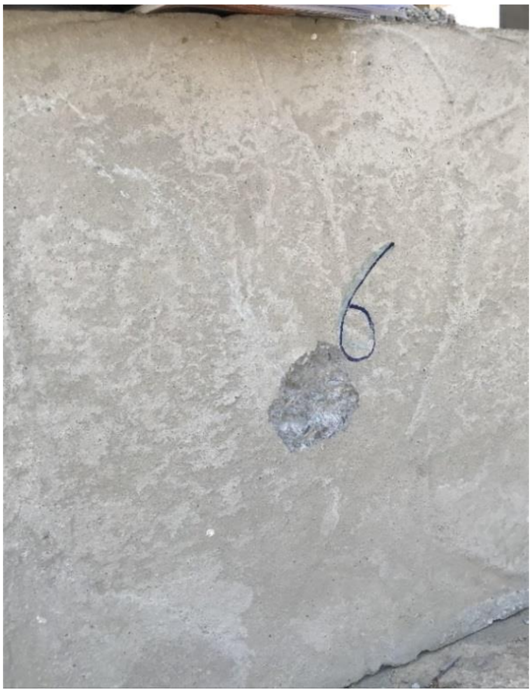
Fig. 15 : Prototype #4 before (left) and after shooting (right) with Polyelectrolyte (10 mg/L).

(a) (b)

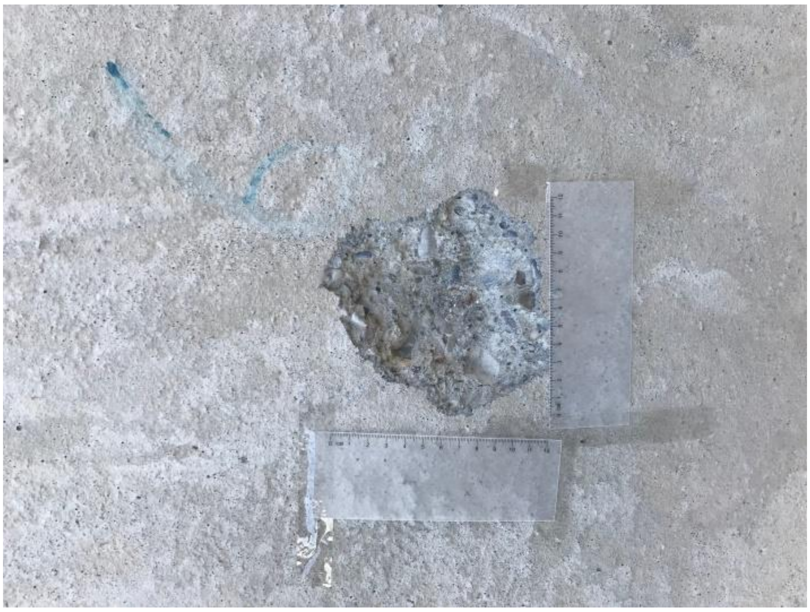
(c)

Fig. 16 : Prototype #5 before (left) and after shooting (right) with Alum +Polyelectrolyte (10+5 mg/L) relatively.

(a)



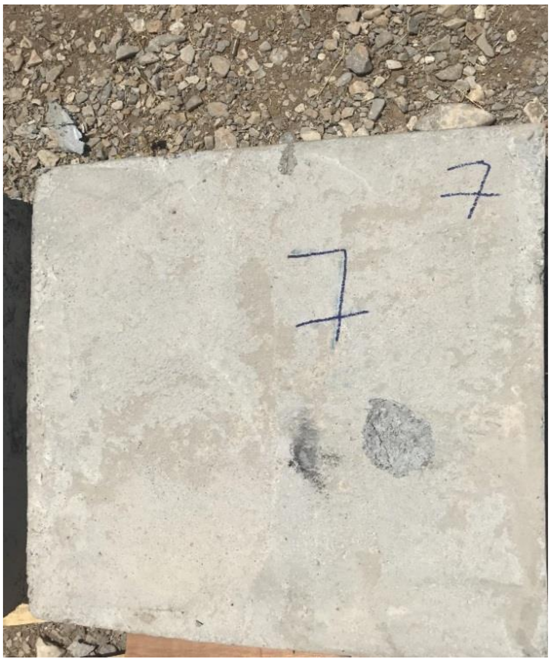
(b)



(c)

Fig. 17 : Prototype #6 before (left) and after shooting (right) with Alum+Polyelectrolyte (5+5 mg/L).

(a)



(b)

(c)

Fig. 18 : Prototype #7 before (left) and after shooting (right) without any coagulant material i.e. (Blank).