ABSTRACT

Biopolymers are naturally occurring polymers that may be or not be chemically modified. They are commonly abundant and sustainable to use in construction. Two biopolymers, starch and alginate, have been used as additives to cement mortar (1:2.75) in dosages of (0.5, 1 and 1.5)% by weight of cement and their effects on cement mortar compressive strength, flexural strength and density were determined. Compressive strength results for cement mortar with Alginate addition showed strength loss at 28-days age mostly at 0.5%. The maximum strength loss for cement mortar with starch at 28 days was at 1.5% starch concentration. Whilst, the 28-days flexural strength was improved for Alginate compared with conventional mortar. However, flexural strength of cement mortar with starch addition was decreased. Density of cement mortar was not affected by the addition of the two biopolymers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 GENERAL

The word polymer literally means many (poly) units (mer). A small, simple chemical unit appears to repeat itself a (very) large number of times in the structure of a polymer molecule or macromolecule. The so-called repeat unit may consist of a single atom, or more commonly a small group of atoms, with the distinctive feature that the repeat units are successively linked to one another on each side by covalent bonds. The simple molecular species from which a chain polymer molecule may be obtained or to which a polymer molecular system may be degraded is called the monomer [1].

The term biopolymer comprises polymers that are:

- Naturally occurring polymers (e.g., starch) which may or may not be processed and/or chemically modified (e.g., carboxymethyl starch).
- Polymers produced in an industrial fermentation process by microorganisms (e.g., lignosulfonates).
- Biodegradable polymers, which can be based on naturally occurring or synthetic polymers (e.g. polyesters).

Biopolymers may be the only product available that can provide certain properties for building materials. Biopolymers also bear the image of being environmentally more acceptable than synthetic polymers produced in a chemical plant [2].

1.2 APPLICATIONS OF BIOPOLYMERS

Biopolymers have a wide range of applications. Many of these applications can be found in the medical field. They can be roughly divided into three categories: drug delivery systems, wound closure and healing products, and surgical implant devices.

Other applications are numerous. Many of the biodegradable polymers have good film forming properties, making them suitable for use in high performance applications as well as in traditional commodity uses. Some applications include food containers, soil retention sheeting, agriculture film, waste bags and the use as packaging material in general. When used as nonwovens, these biopolymers can also be used in agriculture, filtration, hygiene and protective clothing [3].

Applications of biopolymers in construction are widespread and diverse. In some cases, biopolymers offer distinct advantages in performance and/or cost over synthetic polymers, while in other areas biopolymers may be the only product available that can provide certain properties for building materials. Biopolymers also bear the image of being environmentally more acceptable than synthetic polymers produced in a chemical plant, and although this point can be argued it does influence the choice of materials used, especially for interior home building [2].

1.3 AIM OF STUDY

The main objective of the study is to investigate the effects of using different biopolymers with cement mortar. Since those materials are available and not harmful to the environment, using them might be beneficial to quality and properties of cement mortar.

1.4 WORK LAYOUT

Chapter 1 includes general introduction about polymers and biopolymers.

Chapter 2 includes literature review on starch and alginates.

Chapter 3 includes experimental work procedures.

Chapter 4 includes results obtained from testing and discussion.

Chapter 5 includes conclusions and recommendations.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 GENERAL

The large majority of biopolymers act as thickeners or provide water-retention – two properties which often are intrinsic in the same product, the reason being the high molecular weight larger than 100,000 Dalton (Dalton: measure of molecular weight or mass. One hydrogen atom has mass of one Da) that many of these materials possess. Some biopolymers have surface-active properties (e.g., protein extracts) and are efficient air-entraining agents for concrete or mortar, while others containing carboxylic groups (e.g., polyaspartic acid) are powerful set retarders for gypsum and cement. Some biopolymers are listed in Table 2.1[2]:

Table 2.1- Types of biopolymers

Biopolymer	**Uses**
Lignosulfonate	Concrete plasticizer
Melamine, naphthalene condensates	Concrete superplasticizer
Polycarboxylate copolymers	Concrete super plasticizer
Vegetable oils	Carrier fluid
Protein extract	Air-entraining agent
Starch	Viscosifier, water retention
Curdlan	Viscosifier, anti-settling agent

2.2 TYPES of BIOPOLYMERS

2.2.1 Lignosulfonates [2]

Lignosulfonates are produced by chemical processing of lignin, which is a natural biopolymer that occurs in wood and grass. Their chemical composition is shown in Figure 2.1. They are the most common concrete plasticizer, their primary function being dispersion of the cement particles and improvement of concrete flow ability. A secondary effect is that of cement retardation. It has been shown that the phenolic hydroxyl group, which forms part of the highly complicated Lignosulfonate structure, exerts a certain retarding effect on cement, but this retardation is reduced by ethoxylation of the phenolic hydroxyl group.

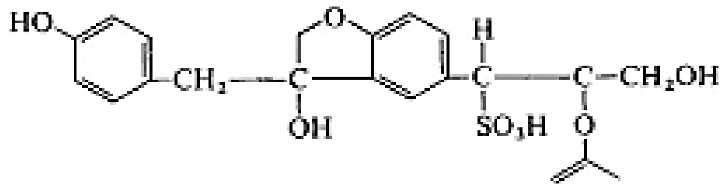

Figure 2.1 The repeating unit of Lignosufonate

The effectiveness of sodium Lignosulfonate on concrete slump at a given water content (w/c=0.68) is shown in at an application of 0.1% Lignosulfonate by weight of cement, slump was increased from 95 mm to 135 mm, indicating improved flow ability and workability of the Lignosulfonate-treated concrete.

The second use of lignosulfonates in concrete is that of water-reduction. A reduction in w/c ratio leads to a higher compressive strength of the concrete, which is highly desirable. In general, the water-reduction achieved with lignosulfonates ranges between 5% and 15%. Typical Lignosulfonate dosages are 0.1–0.5% by weight of cement, and they show a sharp increase in retardation at higher concentrations. Consequently, over dosage in error runs the risk of over-retardation and is undesirable.

2.2.2 Biopolymers from Soil [2]

The anaerobic degradation of plants over many centuries has led to the production of the biopolymers that occur in soil or in deeper sections of the Earth's crust. One of these biopolymers is Humic Acid, which is an important soil constituent and an intermediate in the conversion of vegetation to coal. Because of the complexity of the source materials, it has not yet been agreed upon details of the structure of Humic acid. It is the starting material for graft polymers, which are used in oil well cementing.

Lignite (variously also called leonardite, mined lignin, brown coal or slack) represents a further degraded Humic acid. A natural deposit in North Dakota is the principal source of lignite used in construction applications. It is an inexpensive, multi-functional oil well drilling fluid additive. Initially considered only as thinner for water-based muds, it now serves also for filtrate reduction, oil emulsification, and stabilization of mud properties against the effects of high temperature.

2.2.3 Protein-Based Biopolymers

2.2.3.1 Protein hydrolysates

Protein hydrolysates are extracts obtained by cooking animal blood, hair, hides or hoofs, particularly from cattle, with sulfuric acid or, more recently, with enzymes. After refinement, Protein hydrolysates occur typically as 30–35% active, brown aqueous solutions; their nitrogen content is used to specify their quality. Protein hydrolysates reduce the surface tension of water significantly; they are used to prepare foam concrete. Although they are more difficult to use compared with synthetic foamers and surfactants, they achieve superior foam quality. Protein hydrolysates produce spherical foam bubbles whereas synthetic surfactants typically generate hexagonal bubbles in concrete. Concrete of the same specific density containing spherical bubbles has been shown to provide 20–30% higher compressive strength, compared with concrete containing hexagonal bubbles[2].

2.2.3.2 Casein

Casein is a biopolymer that is found in milk or vegetable products such as soybeans, wheat, etc. and is recovered by acid precipitation. The chemical composition is shown in Figure 2.2. When processed, Casein can be made to look like celluloid, ivory, or artificial horn. It is odorless, insoluble in water, and only with difficulty inflammable.

In the first decades of this century, it was used to make buttons, pins, cigarette-cases, fountain pens, umbrella handles and radio cabinets[4].

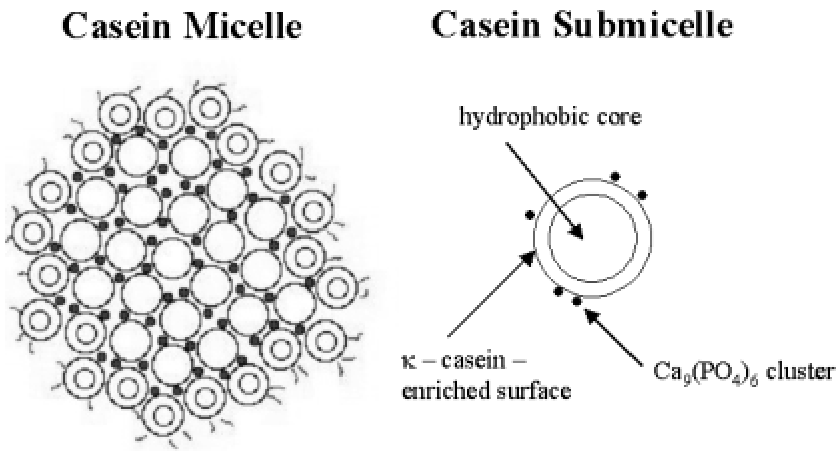

Figure 2.2 Molecular structure of Casein [2]

In construction, casein has found two distinct applications, namely paints and self-leveling underlayment. Self-leveling underlayment is another building application in which casein still plays a significant role on the market. SLU is poured onto uneven floor screeds to provide an even surface before floor carpets are laid and glued with adhesives. SLU is based either on Portland cement, or on mixtures of Portland cement, calcium aluminate cement and anhydrite. Casein provides excellent self-healing properties to SLUs. After being cut with a knife, the scar will immediately close and re-form a completely even surface.

2.2.4 Biodegradable Polymers

Biodegradable materials were used in packaging, agriculture, medicine and other areas. In recent years, there has been an increase in interest in biodegradable polymers. Two classes of biodegradable polymers can be distinguished: synthetic or natural polymers. There are polymers produced from feed stocks derived either from petroleum resources (nonrenewable resources) or from biological resources (renewable resources)[5].

Unlike in many other industries, biodegradability still plays a relatively minor role in construction products. The one exception where biodegradability is of great importance is in well construction. In addition, Polyaspartic acid has been recognized as a cement dispersant. Recently, biodegradable oils such as rape or beet oil, which have replaced the mineral oils are used as surface coating on concrete molds. Their purpose is to prevent concrete adhesion to the wooden mold and to provide an impeccable concrete surface[2].

2.2.5 Starch and Cellulose Derivatives

Starch is one of Nature's three biggest products, the other two being cellulose and chitin. All three are rich in carbon but this carbon is trapped in macromolecular networks. Major starch sources include potatoes, corn, rice and wheat[6]. Starches from whatever source are composed of one or more glucans. The two principal molecular components of starch are the polysaccharides amylose and amylopectin, shown in Figure 2.3. Amylose is composed of long, straight chains of α-glucose, with molecular weights ranging from 10,000 to 100,000 Da. Amylopectin, the main component, consists of a mixture of branched molecules, and has a molecular weight of 40,000 to 100,000 Da [2].

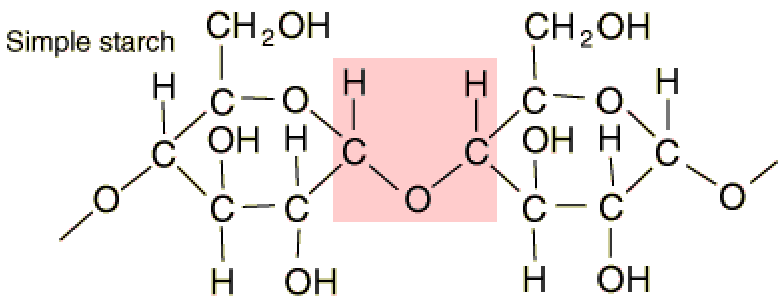

Figure 2.3 Simple starch molecule composition

While starch is used predominantly for food, it is also used as a thickening agent, as an adhesive, for example, the glue on the back of stamps, as a stabilizer, and as a binder. Starch is also often used as a carrier for drugs and as a viscosity modifier in paints. From the chemists' point of view, starch has many appealing properties. For example, its abundant, sustainable, non-hazardous, and biodegradable properties that are becoming increasingly important in these environmentally conscious and sustainability-driven days. Different uses of starch are shown in Table 2.2.

In the construction industry, starch and starch derivatives, usually starch ethers, based on a variety of raw materials, are used as additives for hydraulic binders (e.g., cement, lime, and gypsum). Starch or starch derivatives have a strong effect on the rheology of aqueous systems. In particular, they act as efficient thickening agents, rheology enhancers as a means of improving water retention, and as processing additives and therefore their rapid thickening and rheology-enhancing behavior.

Table 2.2 non-food applications of starches [6]

Adhesives • Hot-melt glues • Stamps, bookbinding, envelopes • Labels (regular and waterproof) • Wood adhesives, laminations • Automotive, engineering • Pressure sensitive adhesives corrugation paper	**Explosives Industry** • Wide range binding agent • Match-head binder	**Paper Industry** • Internal sizing • Filler retention • Surface sizing • Paper coating (regular and color) • Carbonless paper stilt material • Disposable diapers, • Feminine products sacks
Construction Industry • Concrete block binder • Asbestos, clay/ limestone binder • Fire-resistant wallboard • Plywood/chipboard adhesive • Gypsum board binder • Paint filler	**Cosmetic and Pharmaceutical Industry** • Dusting powder • Make-up • Soap filler/ extender • Face creams • Pill coating, dusting agent tablet binder/ dispersing agent	**Mining Industry** • Ore flotation • Ore sedimentation • Oil well drilling mud
Miscellaneous • Biodegradable plastic • Film • Dry cell batteries • Printed circuit boards • Leather finishing		

Moreover, starch ethers have a gluing effect and stabilize the systems (gypsum, cement, or lime basis) to which they are added [6]. Researches were conducted to conclude the effect of starch admixtures on cement mortar.

McCranie and Faulkner et al. showed that Cassava starch was used at concentrations of 0 to 1% by weight of cement in concrete cured at 3, 7, 14 and 28 days using ordinary Portland cement. The maximum strength gain for cassava starch is 22.60% at 3 days at 0.1% starch concentration; and this short-term strength gain was not sustained at 28 days. at 28 days, there was a maximum strength increase of 7.80% with 0.05% cassava starch concentration [7].

Akindahunsi observes the characteristics of cement blended with starch obtained from cassava and maize. The dosages of cassava and maize starch added in different percentages (0, 0.5, 1.0, 1.5 and 2.0 %) by weight of cement to mixes of pastes and concretes. Automatic vicat needle apparatus was used to determine the setting times of cement pastes. The result showed that setting times, and dormant period of hydration was prolonged with shifts in peaks of hydration as concentration of starch increase within the first few hours as shown in Figure 2.4 [8].

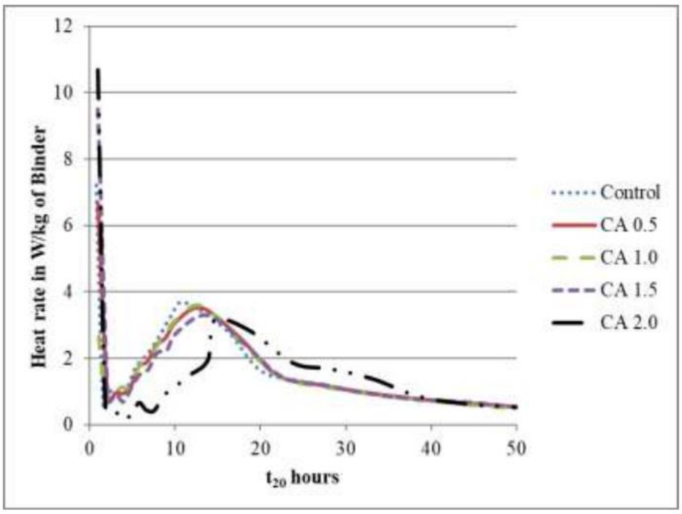

Figure 2.4 Heat rate measured for control and CA admixed with cement pastes [8]

Akindahunsi and Uzoegbo study some properties of concrete, such as strength, oxygen permeability and absorptivity using starch cassava and maize as admixtures. Concrete cubes containing different percentages of the cassava and maize starches by weight of cement (0, 0.5, 1.0, 1.5 and 2.0 %)

were cast. Compressive strength tests were carried out after 3, 7, 14, 21, 28, 56, 90, 180, 270 and 365 days of curing. The strength increase after 1 year over the control for 0.5% and 1.0% are 2.7% and 3.8 % cassava starch concentrations respectively, while 0.5% and 1.0% Maize starch concentrations both gave 1.5 % increase over control [9].

Results obtained by A. Peschard et al. showed that the addition of polysaccharide (0.5% by weight of cement) causes retardation of cement hydration. Results clearly showed that retardation increases with higher polysaccharide-to-cement weight ratio (P/C) [10].

2.2.6 Alginates

"Alginate" is a collective term for a family of polysaccharides produced by brown algae. They are obtained by the alkali extraction of brown seaweed, followed by coagulation in an acid medium and neutralization to alginate salts. Alginates are composed of three blocks:

- Homogeneous β-D-mannuronic blocks …-M-M-M-M-….
- Homogeneous α-L-guluronic blocks …-G-G-G-G-….
- alternating blocks …-M-G-M-G-…. which are linked by 1–4 glycosidic bonds [2].

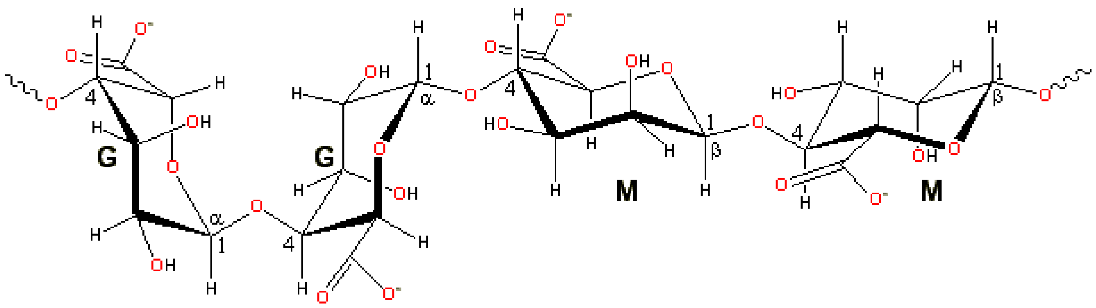

Figure 2.4 Alginates chemical structure

The main industrial applications of alginate as a natural polymeric material are linked to its stabilizing, viscosifying, and gelling properties and its ability to retain water. Alginate is largely used as a Viscosifier in textile printing because of its shear-thinning characteristics. Its use has also been reported to increase color yield and brightness.

In addition, various applications of alginate in the food industry are currently being exploited. The ability of this polysaccharide to stabilize aqueous mixtures, dispersions, and emulsions together with its gel-forming and viscosifying properties represent key features for the use of alginate in food applications. Several alginate-based restructured products (pet food, reformed meat, to name a few) are available on the market for large-scale distribution [11].

Alginate is also used in starch adhesives for making corrugated boards because it stabilizes the viscosity of the adhesive and allows control of its rate of penetration. Soluble alginates (sodium or potassium) are used in coatings on welding rods which are dried at moderate temperatures and in which the alginate remains after drying; this includes organic-type coatings with a high content of cellulosic material and mineral coatings of the "acid" type [12].

Alginates well meet all the requirements for their use in pharmaceutical and medical applications. They have been largely used in wound dressings, dental impression, and formulations for preventing gastric reflux [11]. Moreover, the number of processes in which alginate has been used for cell or enzyme immobilization, on laboratory and larger scales, has increased dramatically in the last few years [12].

As in construction, metal-alginate colloid coating is used in concrete to make the concrete resistant to alkali and magnesium sulphates. Whereas in lightweight concrete, Alginate spheres are uniformly dispersed through the concrete mixture to create a porous structure. Alternative to air entrainment agents or lightweight aggregates[13]. Alginate is also used as an admixture which controls the viscosity of the concrete[14]. When making unfired Clay

Bricks Alginate, in combination within lignin and natural or synthetic fibers is used as a binder to improve the strength of the bricks [13].

Alginates haven't been extensively used in cement mortar but when studied with lime mortar it improved workability (by lowering the value of spread) in comparison with reference mortar, increased the amount of air on the fresh mortar, thus decreasing the density of fresh mortar and also the bulk density of hardened specimens [15].

Sodium alginate has been used to make a new cement paste with cement, seawater, silica, chitosan and hydroxyapatite, found in nature. The new slurry had high thermal stability and low amounts of small crystallite-type portlandite (35.70 nm). in this first study, the new slurry has shown adequate characteristics to contribute to cost effective and environmental-friendly oil well operations [16].

Sodium alginates is also used as a superabsorbent polymer in self-healing concrete. Since the addition of synthetic superabsorbent polymers may lead to a significant decrease in mortar strength, especially when high amounts of them are necessary, the use of Sodium alginate helps to establish a sustainable approach towards self-sealing and -healing concrete without impairing mechanical strength [17].

Strong beneficial effects of applying sodium alginate as a curing compound were observed in terms of microstructure and hydration development. Based on these results, a less porous microstructure and an improved durable cement-based material were achieved which lead to longer service life [18].

3 CHAPTER THREE: EXPERIMENTAL WORK

3.1 MATERIALS USED

3.1.1 Cement

Ordinary Portland cement (O.P.C) manufactured in Iraq with a commercial name of (Tasluga) was used for mortar mixture throughout the present work. This cement complied with the Iraqi specification (IQS, No.5)[19].

The physical properties and chemical analysis of cement used are given in Table (3.1)and (3.2) respectively, Also the compound of cement calculated according to Bogue equation, ASTM C 150 are listed in Table (3.2).

Table 3.1 Physical properties of cement

Physical Properties	Test Result	Limit of IQS No.5
Setting time		
Initial setting (h:min)	2:55	>45 minutes
Final setting (h:min)	3:30	<10 hours
Compressive strength (N/mm^2)		
-7 days	17	>15
-28 days	24	>23
Soundness(mm)	1	<10mm

Table 3.2 chemical properties of cement

Oxides	% by weight	Limit of IQS,No.5
CaO	60.47	-
SiO_2	22.00	-
Al_2O_3	5.00	-
Fe_2O_3	3.00	-
MgO	3.51	<5.00
SO_3	2.51	<2.81
K_2O	0.67	-
Na_2O	0.18	-
Loss on ignition	1.10	<4.00
Insoluble residue	0.70	<1.05
Lime saturation factor	0.86	0.66-1.02
Main compound	%by weight of cement	Limit of IQSNo.5
C_3S	33.39	-
C_2S	37,47	-
C_3A	8.17	>5.00
C_4AF	9.13	-

3.1.2 Sand

AL-Ekhaider natural sand (passes on sieve size No. 4.75 mm) was used as fine aggregate in all mixtures. Some properties of natural fine aggregate are listed in Table (3.3). The grading of fine aggregate is according to (IQS, No.45)[20].

The percentage passes= [W sand passes-W sieve/W sand passes]

Table 3.3 The grading of sand

No. of sieve	**Cumulative percentage of retained sand (%)**	**Cumulative percentage of passing sand (%)**
9.5	0	100
4.75	0	100
2.36	12	88
1.18	35	65
600	49	51
300	82	18
150	99	1

*Fineness modulus (F.M) = 2.7

Table 3.4 Properties of fine aggregate

Properties	Test result	IQS(NO.5) Limit
Sulphates cement SO_3 (%)	0.4	<0.5
Specific gravity	2.7	-----
Absorption (%)	1.2	-----

3.1.3 Starch

AL-Malwiyah starch was used as an additive to the mortar mix. Chemical analysis was done to determine the components of the starch. The results are shown in Table 3.5.

Table 3.5 Chemical analysis of starch*

Z	Symbol	Element	Concentration (ppm)	Abs. error (ppm)
11	Na	Sodium	< 2100	0.0
12	Mg	Magnesium	< 350	0.0
13	Al	Aluminum	< 84	0.0
14	Si	Silicon	17600	90
15	P	Phosphorus	64.0	4.5
16	S	Sulfur	905.9	6.1
17	Cl	Chloride	<2	0.0
19	K	Potassium	4149	60
20	Ca	Calcium	26480	110
22	Ti	Titanium	2433	22
23	V	Vanadium	23.7	3.6
24	Cr	Chromium	41	13
25	Mn	Manganese	95	10
26	Fe	Iron	4442	31
27	Co	Cobalt	18.5	4.6
28	Ni	Nickel	13.1	1.8
29	Cu	Copper	<6.3	0.0
30	Zn	Zinc	13930	20
31	Ga	Gallium	<3.8	0.0
32	Ge	Germanium	<2.3	0.0
33	As	Arsenic	<1.1	0.0
34	Ce	Cerium	<0.8	0.0

35	Br	Bromine	<0.7	0.0
37	Rb	Rubidium	7.6	0.7
38	Sr	Strontium	413.2	2.6
39	Y	Yttrium	10.1	0.5
42	Mo	Molybdenum	<38	0.0
47	Ag	Silver	<4.3	0.0
48	Cd	Cadmium	<4.3	0.0
50	Sn	Tin	<7.1	0.0
51	Sb	Antimony	<6.5	0.0
52	Te	Tellurium	<9.7	0.0
53	I	Iodine	20.8	3.9
56	Ba	Barium	<20	0.0
74	W	Tungsten	<41	0.0
80	Hg	Mercury	8.1	1.2
81	Ti	Titanium	<2.0	0.0
82	Pb	Lead	4.0	1.1
83	Bi	Bismuth	<1.8	0.0
90	Th	Thorium	3.2	0.9
92	U	Uranium	2.1	0.4
Sum of the concentrations			**7.07%**	

***Test was carried out by the Iraq Geological Survey Central Laboratory Department.**

3.1.4 Alginate

Alginate was used as a powder known commercially as Tropicalgin. Results of the chemical analysis of the powder are shown in Table 3.6:

Table 3.6 Chemical analysis of Alginate*

Z	Symbol	Element	Concentration (ppm)	Abs. error (ppm)
11	Na	Sodium	<640	0.0
12	Mg	Magnesium	<10	0.0
13	Al	Aluminum	<180	0.0
14	Si	Silicon	55.5	5.3
15	P	Phosphorus	45.3	1.9
16	S	Sulfur	<2	0.0
17	Cl	Chloride	<0.3	0.0
19	K	Potassium	87	12
20	Ca	Calcium	45.6	4.5
22	Ti	Titanium	<1.5	0.0
23	V	Vanadium	9.4	0.5
24	Cr	Chromium	8.5	3.5
25	Mn	Manganese	9.7	3.1
26	Fe	Iron	9.6	1.7
27	Co	Cobalt	1.4	1.0
28	Ni	Nickel	2.6	0.8
29	Cu	Copper	2.2	0.6
30	Zn	Zinc	4.3	0.5
31	Ga	Gallium	0.4	0.3
32	Ge	Germanium	<0.6	0.0
33	As	Arsenic	<0.4	0.0
34	Ce	Cerium	0.4	0.2

35	br	Bromine	<0.3	0.2
37	Rb	Rubidium	1.5	0.3
38	Sr	Strontium	3.9	0.4
39	Y	Yttrium	10.1	0.3
42	Mo	Molybdenum	<14	11
47	Ag	Silver	6.6	0.9
48	Cd	Cadmium	10.3	0.9
50	Sn	Tin	14.5	0.5
51	Sb	Antimony	21.0	1.3
52	Te	Tellurium	57.6	1.0
53	I	Iodine	71.7	4.2
56	Ba	Barium	40.3	2.2
74	W	Tungsten	2.1	1.2
80	Hg	Mercury	1.8	0.5
81	Ti	Titanium	2.1	0.4
82	Pb	Lead	1.9	0.6
83	Bi	Bismuth	1.5	0.4
90	Th	Thorium	1.3	0.4
92	U	Uranium	2.6	0.3
Sum of the concentrations			0.05%	

***Test was carried out by the Iraq Geological Survey Central Laboratory Department.**

3.2 MIXING PROPORTIONS

The mortar used consists of 1 part cement and 2.75 parts of sand (1: 2.75) proportioned by mass. Portland cement is mixed at 0.47 water/cement ratios that was sufficient to obtain a flow of 80% at 25 drops of the flow table. Percentages of 0.5%, 1% and 1.5% of each of starch and alginate were added to different mixes of mortar and tests were conducted.

3.3 PROCEDURES

Mixing was done mechanically with accordance to ASTM C305-14 [21] and the flow test was used to determine the water content that provides an allowable flow level for cement mortar. According to ASTM C1329-03 [22] the quantity of water, measured in milliliters, shall be such as to produce a flow of (110 ± 5)%. Flow is the resulting increase in average base diameter of the mortar mass, expressed as a percentage of the original base diameter. The test was carried out with accordance to ASTM C1437 [23]

Three specimens were molded for each test, age and additive percentage and were kept in a moist ambient condition for 24 hours before removing them from the molds. Then they were cured in water for the desired period until the time of testing.

3.4 TESTING

3.4.1 Compressive strength

Compressive strength was obtained with accordance to ASTM C109 [24] on (5 cm *5 cm *5 cm) cube specimens with ages of (7 and 28) days. Six specimens were tested for each mix immediately after their removal from water**.**

3.4.2 Flexural strength

Three prismatic specimens (4 cm *4 cm *16 cm) were tested at age 28 days to determine the flexural strength of cement mortar with different additives. The test was conducted with accordance to ASTM C348 [25].

3.4.3 Density

Density of cement mortar was also determined by dividing weights of the specimens on their volume. Saturated surface dry cubic specimens were tested at 7 and 28 days age.

4 CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 COMPRESSIVE STRENGTH

The compressive strength test results at 7 days showed that starch addition of 0.5 and 1.5% have 10% and 20% strength loss respectively compared with the reference mix. Whereas, 1% addition has strength gain of 32% over the reference. Unlike the Alginate, where it gained 53%, 32% and 11% of its compressive strength over reference mix. This is shown in Figure 4.1.

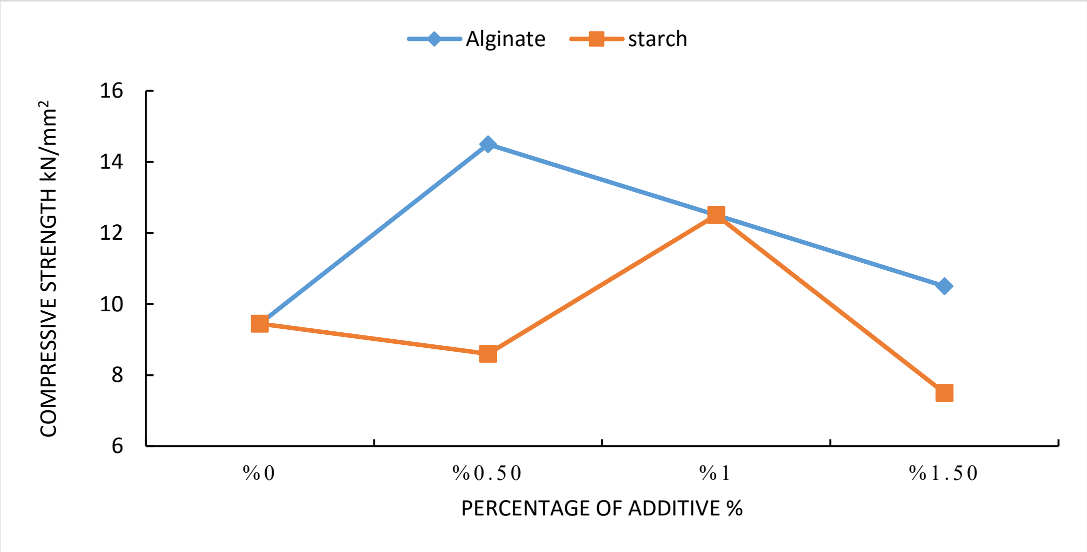

Figure 4.1 Compressive strength test results at 7 days age

At 28 days the strength loss for starch addition percentages of 0.5, 1 and 1.5% are 12.3, 18.6 and 34.1% respectively compared with the reference mix. This may be due to the fact that starch delays the hydration process [8] therefore the strength development did not reach 90% as for the reference mix.

While cement mortar with Alginate lost 42%, 24% and 37% of the compressive strength at (0.5, 1 and 1.5) % of addition respectively at the same age as shown in Figure 4.2. The reason to this might that Alginates increase porosity of cement mortar[26].

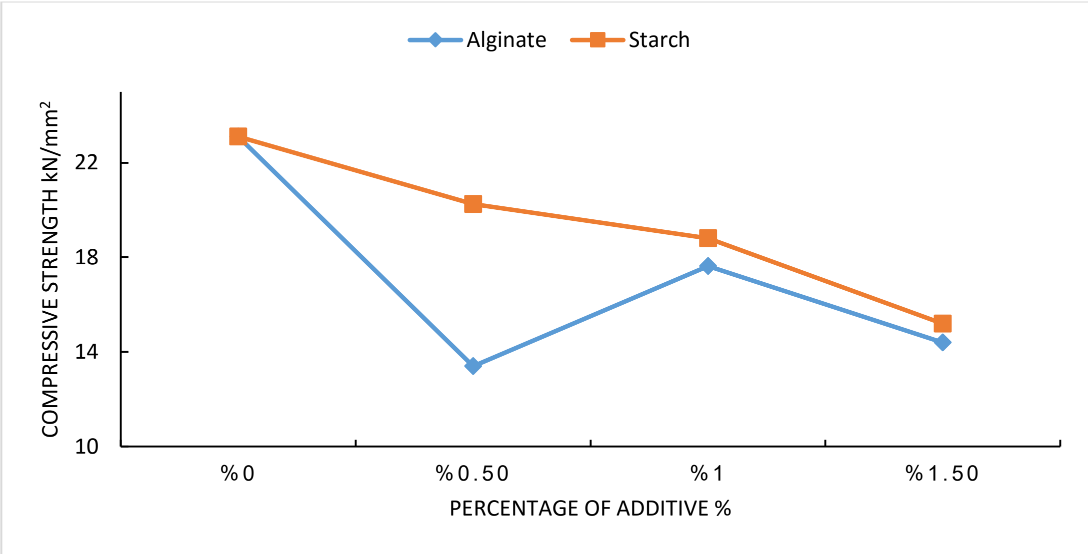

Figure 4.2 Compressive strength test results at 28 days age

The effect of additives on the compressive strength of cement mortar through time is compared with the compressive strength of the reference mix in Figure 4.3 and Figure 4.4.

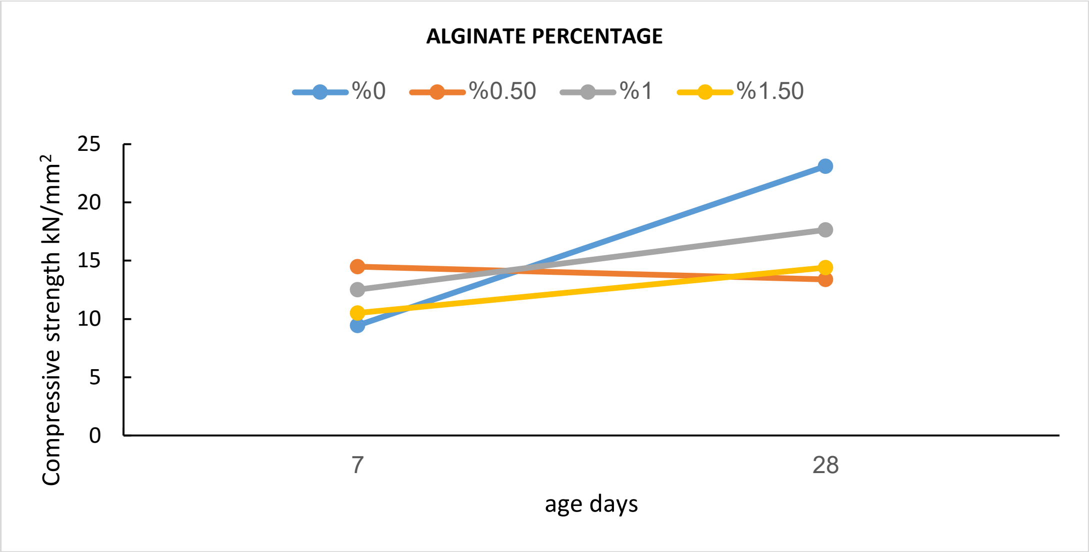

Figure 4.3Effect of Alginate on compressive strength with age

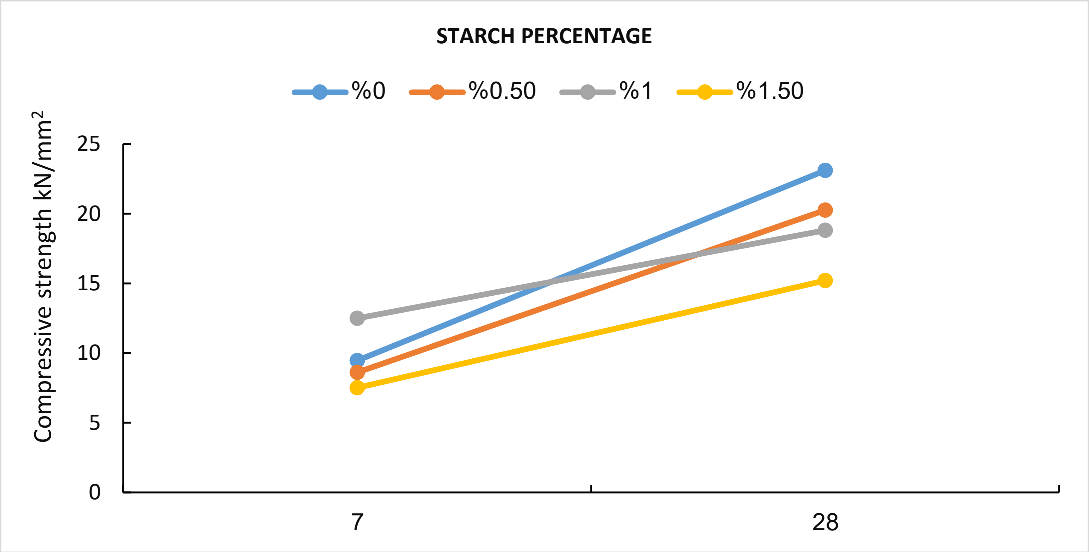

Figure 4.4 Effect of starch on compressive strength with age

Results are summarized in Table 4.1. Each entry is the average of three results obtained from the test.

Table 4.1 Compressive strength test results

Percentage of addition (%)	**Compressive strength (kN/mm^2)**			
	Alginate		**Starch**	
	7 days	**28 days**	**7 days**	**28 days**
0%	9.45	23.1	9.45	23.1
0.5%	14.5	13.4	8.6	20.25
1%	12.5	17.63	12.5	18.8
1.5%	10.5	14.4	7.5	15.2

4.2 FLEXURAL STRENGTH

Flexural strength of cement mortar with biopolymers was determined at the age 28 days. The addition of Alginate appear to have beneficial effect on flexural strength thought at the cost of compressive strength decrease. The addition of (0.5, 1 and 1.5) % Alginate yielded (7.6, 11.8 and 8.7) % increase of the flexural strength of the reference mix respectively. On the other hand, Starch addition decreased the flexural strength of cement mortar. The loss was (14.2, 11.45 and 72.9) % for (0.5, 1 and 1.5) % starch addition respectively. This is shown in Figure 4.5.

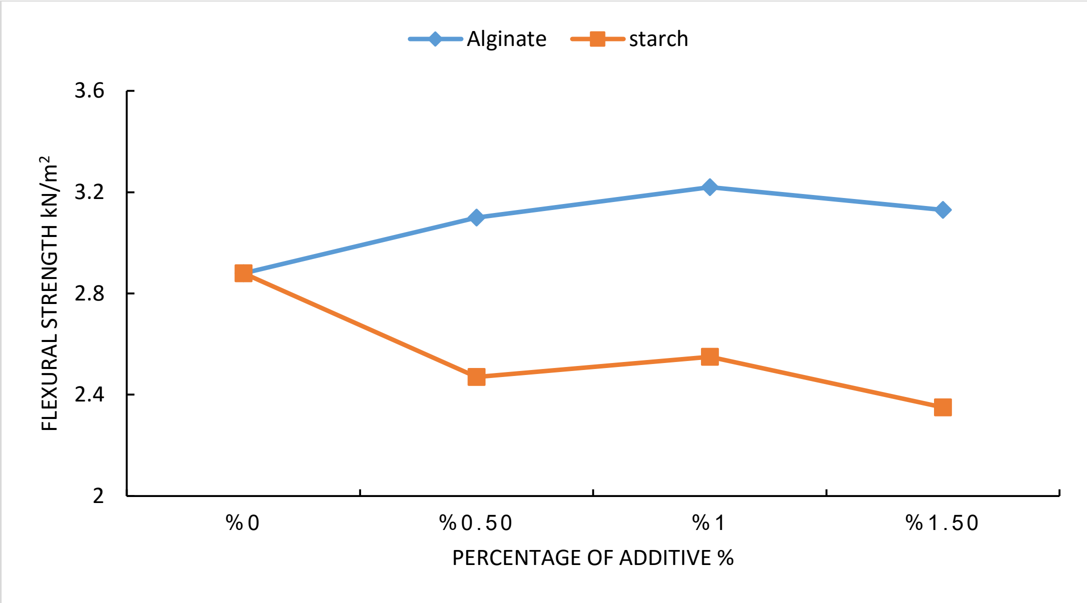

Figure 4.5 Flexural strength test results at 28 days age

Results are summarized in Table 4.1. Each entry is the average of three results obtained from the test.

Table 4.2Flexural strength test results

Percentage of addition (%)	Flexural strength (kN/mm^2)	
	Alginate	**Starch**
0%	2.88	2.88
0.5%	2.47	3.1
1%	2.55	3.22
1.5%	1.3	3.13

4.3 DENSITY

Density of cement mortar at ages 7 and 28 was not affected by the addition of any of the biopolymers as is clearly shown in Figures 4.6 and Figure 4.7

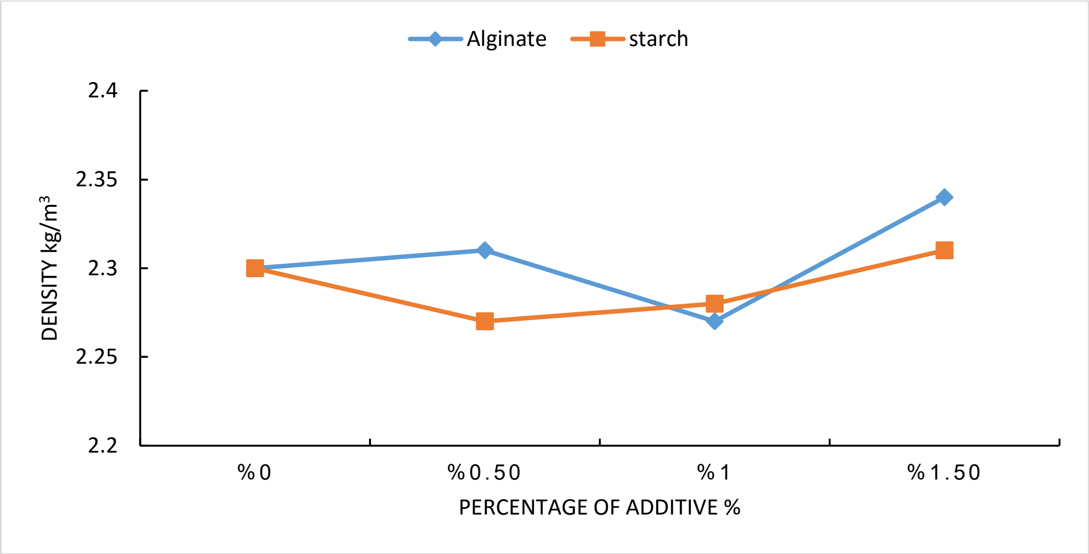

Figure 4.6 Density test results at 7 days age

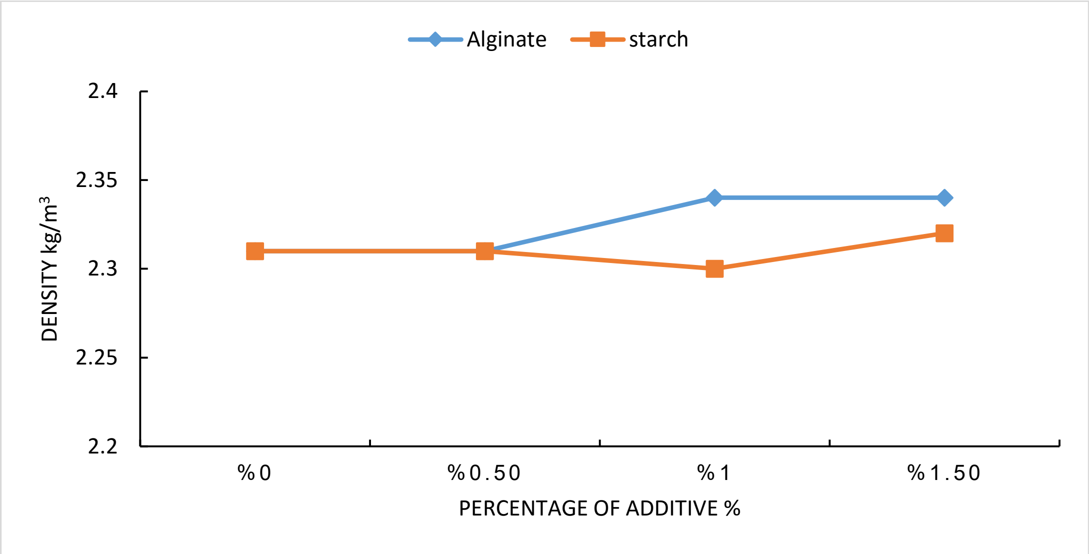

Figure 4.7 Density test results at 28days age

Density also remained unaffected through time and this can be seen in Figures 4.8 and 4.9.

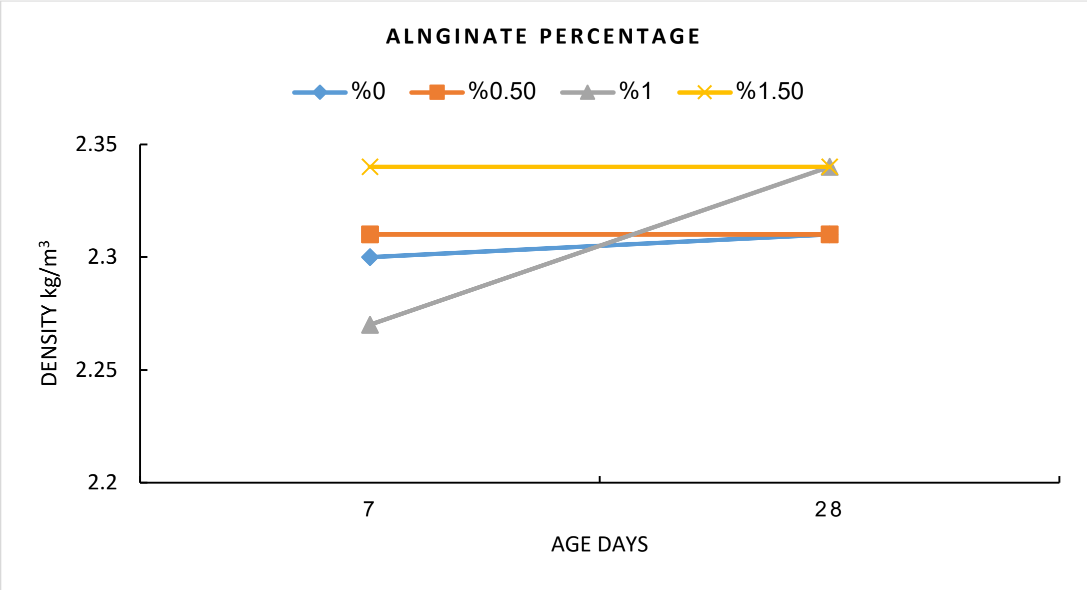

Figure 4.8Effect of Alginate on density with age

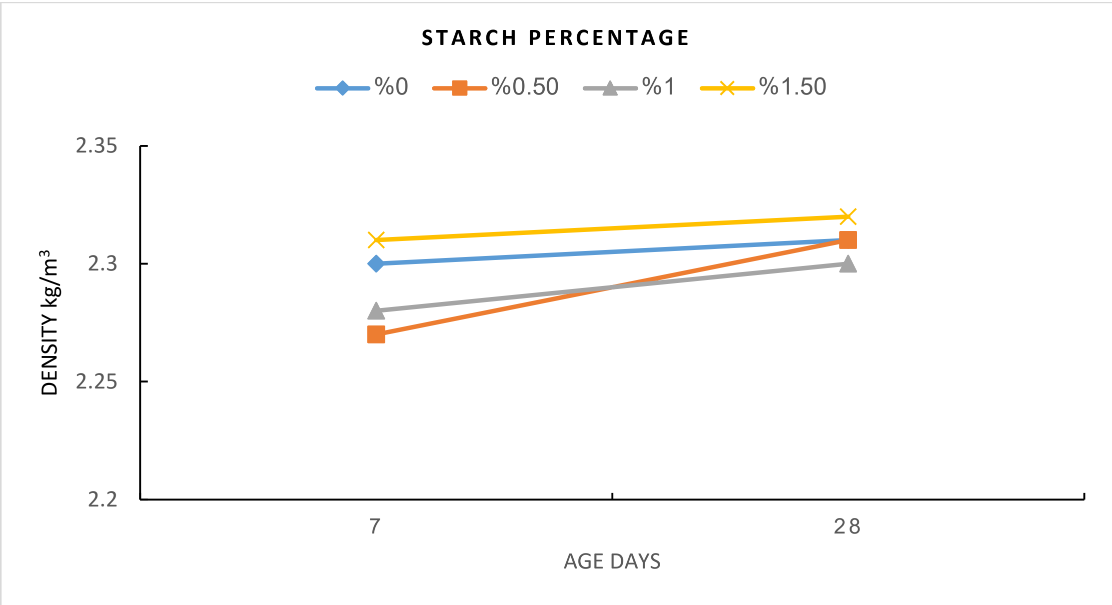

Figure 4.9 Effect of strach on density with age

Test results are summarized in Table 4.3.

Table 4.3 Density test results

Percentage of addition (%)	**Density (g/cm^3)**			
	Alginate		**Starch**	
	7 days	**28 days**	**7 days**	**28 days**
0%	2.3	2.31	2.3	2.31
0.5%	2.31	2.31	2.27	2.31
1%	2.27	2.34	2.28	2.3
1.5%	2.34	2.34	2.31	2.32

5 CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Starch and Alginate exhibit similar effects in cement mortar at the concentrations reported, for both have no effect on density and adverse effect compressive and flexural strength at 28 days age.

Compressive strength of mortar with Alginate addition at 7-days age was compared with that of reference mortar. The results increased with increase in Alginate percentage showing the best result at addition of 0.5% Alginate (50% increase). While the values obtained for cement mortar with starch addition decreased with increase in the percentage of starch except for 1% addition where it increased by about 40%.

At 28-days, it was found that the compressive strength for all mortars containing both alginate and starch decreased compared to reference mortar, significant for samples with starch addition.

The Alginate addition yielded marginal gain in the fexural strength of cement mortar. While starch addition adversely affected the results.

The addition of starch and alginate showed no effect on density at ages 7 and 28 days which makes these materials extremely interesting.

5.2 RECOMMENDATIONS FOR FUTURE WORKS

1. Using biopolymer materials with supplementary cementitious material.

2. Determining the effect of biopolymers on the hydration process using scanning electron microscopy pictures.

3. Carrying out further studies on the effects of biopolymers on concrete.

4. Investigating the effect of biopolymers on other properties of cement mortar and concrete (i.e. absorption)

REFERENCES

[1] P. Ghosh, *Polymer Science*. Kolkata: Polymer study centre, 2006.

[2] J. Plank, *Applications of Biopolymers in Construction Engineering*, vol. 49, no. 89. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2005.

[3] K. Van de Velde and P. Kiekens, "Biopolymers: overview of several properties and consequences on their applications," *Polym. Test.*, vol. 21, no. 4, pp. 433–442, 2002.

[4] T. Lenau, "Casein formaldehyde," *plastic museum*, 1996. [Online]. Available: http://www.designinsite.dk/htmsider/m0980.htm.

[5] I. Vroman and L. Tighzert, "Biodegradable Polymers," pp. 307–344, 2009.

[6] C. Datta, "Starch as a Biopolymer in Construction and Civil Engineering," in *Handbook of Bioplastics and Biocomposites Engineering Applications*, Hoboken, NJ, USA: John Wiley & Sons, Inc., 2011, pp. 317–344.

[7] K. D. McCranie, M. Faulkner, D. French, G. A. Daddis, J. Gow, and A. Long, "Book Reviews," *J. Strateg. Stud.*, vol. 34, no. 2, pp. 281–293, Apr. 2011.

[8] A. A. Akindahunsi, "INSIGHT INTO THE HYDRATION AND MICRO-STRUCTURAL PROPERTIES OF EXTRACTED STARCH FROM CASSAVA AND MAIZE," *Acta Tech. Napocensis*

Civ. Eng. Archit., vol. 61, no. 1, pp. 91–119, 2018.

[9] A. A. Akindahunsi and H. C. Uzoegbo, “Strength and Durability Properties of Concrete with Starch Admixture,” *Int. J. Concr. Struct. Mater.*, vol. 9, no. 3, pp. 323–335, Sep. 2015.

[10] A. Peschard *et al.*, “Effect of polysaccharides on the hydration of cement paste at early ages,” *Cem. Concr. Res.*, vol. 34, no. 11, p. 2153, 2007.

[11] I. Donati and S. Paoletti, *Alginates: Biology and Applications*, vol. 13. Berlin, Heidelberg: Springer Berlin Heidelberg, 2009.

[12] D. J. McHugh, “Production and utilization of products from commercial seaweeds,” Food and Agriculture Organization of the United Nations, rome, 288, 1987.

[13] C. Dove, “Exploring the use of seaweed biopolymers in composite construction products,” University of Strathclyde, 2017.

[14] R. W. H. Chan and C. E. P. P.N., “Report on concrete admixtures for water proofing construction,” 1999.

[15] T. Zizlavsky, M. Vysvaril, and P. Rovnanikova, “Rheological characteristics of aerial lime-based pastes with addition of biopolymers,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 385, no. 1, p. 012067, Jul. 2018.

[16] I. M. G. dos Santos, D. O. Santos, A. R. Cestari, J. F. S. Ribeiro, J. do P. H. Alves, and A. B. Ferreira, “A new cement slurry modified with chitosan/alginate interpenetrating networks and hydroxyapatite - structural characteristics after long-term contact with hyper-saline produced water from oil well operations,” *Matéria (Rio Janeiro)*, vol. 22, no. 1, 2017.

[17] A. Mignon, P. Dubruel, S. Van Vlierberghe, and N. De Belie, “Biopolymers as novel tool for self-sealing and self-healing of

mortar," in *Materials Research Society Symposium Proceedings*, 2016, vol. 1813, pp. 28–33.

[18] J. Zlopasa, E. A. B. Koenders, and S. J. Picken, "Using bio-based polymers for curing cement- based materials," *AMS 14 Proc. Int. Conf. Ageing Mater. Struct.*, vol. 1, no. May, pp. 220–226, 2014.

[19] Central Organization for Standardization and Quality Control, "Portland Cement," in *Iraqi standard specification No.5*, Baghdad: Ministry of Planning, 1984.

[20] Central Organization for Standardization and Quality Control, "Aggregates of Natural Resources used for Concrete and Construction," in *Iraqi standard specification (IQS) No.45*, Baghdad: Ministry of Planning, 1984.

[21] ASTM, "Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency," *ASTM Int.*, vol. 04, no. c305, pp. 1–3, 2014.

[22] ASTM, "Standard Specification for Mortar Cement," *ASTM Int.*, vol. 04, no. C1329, pp. 1–7, 2003.

[23] ASTM, "Standard Test Method for Flow of Hydraulic Cement Mortar," *ASTM Int.*, vol. 04, no. C1437, pp. 1–2, 2015.

[24] ASTM, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars," *ASTM Int.*, vol. 04, no. C109, pp. 1–10, 2012.

[25] ASTM, "Standard Test Method for Flexural strength of hydraulic-cement mortars," *ASTM Int.*, vol. 04, no. C348, pp. 1–6, 2002.

[26] L. A. Coelho, W. T., Fernandes, J. M., Vieira, R. S.c, Thurmer,, M. B., Santos, "be Modifications on the Properties of a Calcium Phosphate Cement by Additions of Sodium Alginate," pp. 1822–1827, 2012.

الخلاصة

البوليمرات العضوية هي بوليمرات موجودة في الطبيعة وقد تتم معالجتها كيميائياً. تم استخدام اثنين من البوليمرات، النشاء والالجينات، كإضافات لمونة السمنت بنسب (0.5 , 1 و1.5) بالمئة من وزن السمنت وتم تحديد تأثيرها على مقاومة الانضغاط ومقاومة الشد والكثافة. اظهرت نتائج فحص مقاومة الانضغاط لمونة السمنت المضاف اليها الالجينات نقصاناً بعمر ثمانية وعشرين يوماً وخاصة عند إضافة نسبة 0.5%. بينما كان اعلى نقصان في مقاومة الانضغاط لمونة السمنت المضاف اليها النشاء بنسبة 1.5%. اما مقاومة الشد فقد تحسنت لمونة السمنت المضاف اليها الالجينات مقارنة بمونة السمنت الاعتيادية ولكنها انخفضت في حالة مونة السمنت المضاف اليها النشاء ولم تتأثر الكثافة بإضافة أي من المادتين.