Civil Engineering Infrastructures Journal xx,xx

DOI: 10.22059/ceij.2025.388293.2218

Comparative study on the action of different natural extract admixtures in concrete on workability and compressive strength properties

Mohammed, A.A.[1*], Hamid, N.A.[2]

College of Engineering, University of Sulaimani, Sulaimani, Krg. Iraq

[1]E-mail: azad.mohammed@univsul.edu.iq, [2]E-mail: niyan.hamid@univsul.edu.iq

* Corresponding author

Received: 06/01/2025

Revised: 30/05/2025

Accepted: 03/10/2025

Abstract: In this study, comparative action of five natural extract admixtures on workability and strength properties of concrete of 35 MPa strength and 95 mm slump was investigated. Compressive strength test was arranged to search for the optimum dosage of admixture and for this purpose a total of 22 concrete mixes were prepared. Results indicate that there is no good action of gum Arabic admixture to enhance compressive strength. Maximum strength enhancement is for the mix contained 0.3% pomegranate extract admixture which is 37.8% and maximum strength loss is for the mix containing 0.2% gum Arabic admixture (15.4%). Optimum dosage of the natural admixture was found to be 0.3% for mulberry and pomegranate extracts, 0.25% for grape extract, added by cement weight and equal to 35% added as water replacement for cactus extract. On the optimized mixes, results of tests show that there is an improvement in the homogeneity of the hardened concrete leading to the compressive strength enhancement except for the mix containing gum Arabic. Workability in terms of slump was enhanced because of using different extracts in concrete except cactus. Best natural admixture to enhance strength is pomegranate extract and the best one for workability is gum Arabic.

Keywords: Cactus extract, Compressive strength, Gum Arabic, Pomegranate extract, Natural admixture

1. Introduction

Before the invention of Portland cement in the nineteenth century, lime mortar was an abundant binder to hold building units (mainly bricks and stones) together. Careful inspection of the binders used in historical structures informed us that different bio admixtures were utilized for the preparation of lime mortar, and this procedure was for the purpose of durability enhancement. Some reports indicate that mortar used in the historical structures contained organic adhesive such as egg white, blood, milk of figs, egg yolk, casein, animal glue, beer vegetable juices, tannin, urine etc. (Thirumalini and Sekar, 2013). On the other hand, development of chemical polymer admixtures to be used in Portland cement concretes was a revolutionized event in the concrete industry and this was led to the invention of high-performance concretes. Consequently, natural admixtures had gained no importance by the past researchers worked on developing novel concretes because chemical admixtures proved their effectiveness to produce high performance concretes. There is no doubt that the production of different admixtures is a chemical process and the process usually accompanied with many environmental problems. The process, identical to many others, is accompanied with the greenhouse gas emission to the atmosphere, consuming energy and natural resources. As an alternative, researchers are thinking about developing alternatives of chemical admixture and natural or bio-admixture seems to be a good candidate.

As an alternative, researchers are thinking about developing alternatives of chemical admixture and natural or bio-admixture seems to be a good candidate.

If one dose not categorize sugar as a natural admixture, which was used as a retarder for delaying setting time of cementitious compounds, one of the earlier encouraged attempts for using natural admixture in Portland cement concrete is that made by Chandra and Aavik in 1983. They reported that black gram acts as an air-entraining agent and able to improve the adhesiveness and hydrophobicity of cement mortar and concrete. Since that time, many research plans have been arranged to disclose the true action of different bio admixtures in Portland cement based compounds. Below, the reader will find the results of these works briefly. In this review, only those studies are considered that used natural admixtures without chemical treatment during their processing, such as sugar, because the topic of our study is on the natural admixture without any treatment to be an alternative of chemically produced ones. The main purpose of this task is to produce an environmental-friendly or clean concrete to be used instead of the chemical admixture contained concretes.

Worldwide researchers involved with the use of sustainable materials for cement based composites. For instance, Ahmed et al. (2024) performed tests to investigate the action of replacing fly ash with recycled brick waste powder (RBWP) to produce geopolymer concrete. Results show that on replacing 40% and 100% fly ash by RBWP, flexural strength improved by 39%. Also, abrasion resistance was enhanced when fly ash is completely replaced with RBWP while sorptivity and water absorption increased by about 128% and 240%, respectively.

Some natural admixtures such as Okra extract (Hazarika et al., 2016) can work as an air-entraining admixture, while blue gum is able to reduce shrinkage cracking even when the concrete is subjected to direct heat from the sun (Woldemariam et al., 2015). This investigated bio-admixture exhibits viscosity enhancing property. In comparison to the reference cement paste, Hazarika et al. (2018) found that okra extract contained cement pastes have shorter setting time which was attributed to increasing hydration rate of cement particles as supported by FTIR spectroscopic test. This behavior is in contrast with the majority of natural admixtures in which they delayed setting of cement. Also, there was a compressive strength enhancement of mortar and concrete because of using okra extract.

In a study, Woldemariam et al. (2014) found that using cypress plant extract is able to increase strength at a constant slump, and increase workability at a constant liquid to cement ratio. Ramesh Babu and Neeraja (2017) observed that using 0.25% dosage of an admixture prepared by mixing white albumen and yellow yolk of broiler hen egg has very much significant effect on compressive strength and splitting tensile strength tested at different ages.

Yildirim and Altun (2012) found that sugar cane molasses has water reducing and retarding effect in concrete. In a recent study, Acharya and Gyawali (2024) found that natural molasses is a better retarder, milder plasticizer, and has stronger viscosity-enhancing capacity than superplasticizer (SP). A similar compressive strength is obtained with the optimum content of the two admixtures. The splitting tensile strength of concrete containing natural admixture was more as compared with that containing SP. On the other hand, concretes with molasses were observed as affected from the harmful chemical reactions more compared to control concretes (Akar and Canbaz, 2016). It was found that sugar cane molasses extends both initial setting and final setting times. All properties of concrete were influenced by addition of this molasses in concrete. Also, the molasses serve as a water reducing agent (Reddy, 2023).

In a study, Kassa (2019) found that the addition of molasses into cement paste is able to delay the setting time of cement paste with a minimum of 380 min and a maximum of 990 min, and in turn reduces rate of strength development at early ages. Based on his data, this admixture enhances the compressive strength at the age of 28 days by 4.5–16.52%. An observation close to this was made by Meron (2019). She obtained 13.54% enhancement in compressive strength of concrete at 28 days on using 0.3% molasses compared with the control specimen.

Experimentally, Afroz et al. (2020) found that using arrowroot delayed setting time of cement paste and increased workability of fresh concrete mix. Also, durability parameters were enhanced for concrete with arrowroot admixtures as confirmed by sorptivity, rapid chloride permeability test (RCPT) and rapid migration test (RMT).

With regard the cactus (Opuntia ficus-indica) extract, several published works is available which gives useful information about the action of this admixture in concrete. Amaran and Ravi (2016) observed that cactus extract can improve the plasticity of cement mortar, and both workability and compressive strength of concrete. Also, cactus has the ability to delay the cement setting time and this was attributed to moisture holding capacity of carbohydrates present in the cactus. Tests by Aquilina et al. (2018) show us that inclusion of cactus in cement-based mortar is able to increase compressive strength. Also, using this extract increased setting time a consequently cactus could be potentially used as retarding agents.

Chandra et al. (1998) found that cactus extract increases the plasticity of cement mortar and improves water absorption and freeze-salt resistance. Further, Shanmugavel et al. (2020) reported that cactus extract containing polysaccharides which enhance the water retention of the concrete, preventing the early drying of the concrete mix and thereby reducing shrinkage cracks. Also, cactus extract is able to improve concrete workability and this was attributed to viscosity enhancement. Their results also evidenced that concretes with cactus extract exhibit enhanced mechanical properties and durability characteristics.

If one considers gum Arabic Karroo (GAK) admixture, this material contains soluble sugars, and hence acts as a set-retarding water reducing admixture (Mbugua et al., 2016). Test data by Mbugua et al. (2016) show that GAK is able to increase final setting time by 6 h above control. Also, due to reducing water to cement ratio, strength was increased and consequently GAK has the ability to be used as a water reducing admixture in cement mortar. According to Dakas et al. (2017) experiment, there was gradual rise in workability due to the addition of gum Arabic from 0.4% to 0.8% (by cement weight). Compressive strength of concrete was also increased when compared to the control mix without admixture and the optimum dosage of the admixture was found to be 0.8%.

In an experiment, Elinwa et al. (2018) observed that the addition of gum Arabic to concrete is able to improve its performance because of existing minerals such as sepiolite, palygorskite and mordenite. The compressive strength was found to increase as the dosage of GA was increased and the adequate dosage was between 0.50% and 0.75%. According to Mouanda et al. (2021) experiment, addition of gum Arabic in concrete delayed the initial and final times of cement, improved workability of fresh concrete, and enhanced mechanical properties of hardened concrete.

It is interested herein to talk about grape extract. Tests by Mahmood et al. (2023a) indicate a continuous increase in slump of fresh concrete with increasing grape extract (GE) up to 0.66%. Up to 0.55% GE addition, there was no compressive and flexural strengths loss, but 16.2% loss of splitting tensile strength and 11.33% loss of elastic modulus were observed. The optimum dosage of GE for compressive strength enhancement was found to be 0.22% in which there was 18.5% enhancement. Mahmood et al. (2023b) results showed a continuous increase in slump value with increasing mulberry extract dosage reaching 122% at 0.66% extract content (by cement weight). Compressive and flexural strengths were increased by 27% and 15%, respectively when the extract is used by 0.33%. However, splitting tensile strength was reduced continuously with increasing the extract in the mix and elastic modulus was reduced up to a dosage of 0.33%. In another paper (Mahmood et al., 2021), these authors conducted an experiment to show the comparative action of two natural extracts, mulberry and grape and superplasticize on properties of concrete. Increasing of workability and reduction in water absorption were observed when the two

natural admixtures were added to concrete. An enhancement of compressive strength tested at 3, 7, and 28 days and the 28 days modulus of elasticity were observed, but there was a splitting tensile strength reduction.
Recently, a comparative experimental study was performed by Abu-Bakr et al. (2024) to show the action of five different extracts and superplasticizer on fundamental properties of cement mortar. Addition of all natural admixtures to cement mortar enhanced compressive and flexural strengths and decreased water absorption. Grape extract and pomegranate extracts enhanced flow of fresh mortar, and 0.4% grape extract is the optimum type of natural extract addition to improve mechanical and flow ability properties. With regard the shear-bond strength, pomegranate extract is the best one when added by 0.3% since there was 155.9% enhancement.
More recently, and in an innovative attempt, Mohammed et al. (2024) worked on the properties of concrete contained prosopis farcta extract admixture (PFEA). Based on this experiment, PFEA is a strong retarder, in which the initial and final setting times were increased by 2.74 and 3.34 times when 35% and 30% PFEA as water replacement is used respectively. Slump of fresh concrete was reduced by 15–78% and compressive strength of hardened concrete was increased by 36.4–43.2%. Also, PFEA is able to enhance splitting tensile and flexural strengths and reduce drying shrinkage.
From the foregoing review, one can observes that the majority of research studies were focused on one type of natural admixture and, as the authors think, there is a few numbers of comparative studies deal with concrete properties using two different types of natural extracts. Also, there is one comparative study on using five different extracts to assess properties of cement mortar; therefore, there is a need for further research on concrete to illustrate the comparative action of different natural admixtures. Compressive strength is considered as the most important structural properties of concrete and there are many properties could be related well with compressive strength. ACI 318 Code (2019) provided equations to calculate different senses of concrete such as elastic modulus, flexural strength, shear strength, etc. So, majority of concrete properties of concrete will follow compressive strength changes, enhancing or reducing. Therefore, this study focuses of compressive strength and related properties represented by the elastic modulus and compressive stress-strain relationship, for concrete mixture modified by different natural extract admixtures. From measuring compressive stress-strain relationship, compressive strength, elastic modulus, and strain corresponding to peak stress were assessed. Also, the nature of post peak response and residual strength (if any) could be assessed.
The novel attempt of this experiment will pave way to produce clean, and environmental-friendly concrete mixtures to be used instead of the currently used chemically-based admixtures for different applications. Also, the present experiment will fill gap of knowledge on the environmental-friendly concretes containing natural admixture and pave way for further research on this important issue of concrete technology.

2. Materials

Materials used for casting concrete specimens were cement, fine aggregate, coarse aggregate, water, superplasticizer and natural extract admixtures. Ordinary Portland cement (Type CEM I 42.5R) produced by Tasluja Company- Kurdistan was used throughout the experiment. Crushed stone coarse aggregate was used for concrete mixes was with a nominal size equal to 12.5 mm. For the coarse aggregate, saturated surface dry bulk specific gravity was 2.65, loose bulk density 1430 kg/m^3, and dry rodded bulk density was 1560 kg/m^3. Sieve analysis was conducted on coarse aggregates according to ASTM C136/C136M specification (2019) and the results are shown in Fig. 1. One can find that the grading conforms to the BS 882 (1992) limits. Natural river sand passing by 100% on of 4.75 mm sieve, of fineness modulus equal to 3.05, saturated surface dry specific gravity equal to 2.66, loose bulk density 1700 kg/m^3 and dry rodded bulk density equal to 1850 kg/m^3. Fig. 1 shows grading of fine aggregate and the limits of BS 882 (1992), from which one can find that the fine aggregate conforms to the specification limits. It should be noted that the material finer than 75 microns was 1% smaller than 3% recommended by the specification. Potable drink water was used for mixing concrete and curing of specimens.

With regard the admixtures used in this study, five different natural extract admixtures have been used beside a chemical admixture (high range water reducer). A process for manufacturing mulberry, grape and pomegranate admixtures was discussed in some detail by Abu-Bakr et al. (2024) and illustrative pictures were also given. Chemical composition and mineral content of these two admixtures are given in Mahmood et al. (2021). For mulberry, solid content is 62.07% and specific gravity is 1.35 while for grape solid content is 58.84% and specific gravity is 1.335. Tests were performed by the authors in the laboratory on the pomegranate molasses and specific gravity was found to be 1.352. Gum Arabic admixture was prepared as follows. Gum Arabic taken from market (Fig. 2a) was subjected to grinding using electrical juice maker device two produce a powder (Fig. 2b). Water was added in the ratio of 1:1 (by weight) and well mixed for ten minutes and slurry like liquid was obtained as shown in Fig. 2c. Test was made to measure the specific gravity and found to be equal to 1.1.

To prepare cactus extract, leaves of cactus planet (see Fig. 3a) in a park located in Sulaimani city was collected. Firstly, after replacing the skin of the leaf (see Fig. 3b) it has been cut into elongated pieces of an average width of 10 mm and then further cut into small pellets of about 5 mm width (see Fig. 3c). Water was added in a ratio of 1:1.25 (cactus pellet: water) and left to soak them for 24 hrs. The mixture then well squeezed and filtered on a clean cloth and well pressed to separate the liquid from the solid material. The final form of the cactus extract ready for use is shown in Fig. 3d. The produced extract dissimilar to the four others is a thick liquid contains a relatively large amount of continuous natural fiber embedded is a liquid and according to test data specific gravity of this extract was found to be 0.96. Chemical admixture (superplasticizer) used was Poly carboxylate ether based water reducing admixture, color was light yellow, specific gravity was 1.075, and solid content was 40%.

3. Concrete mixture proportion

In this study, for control mixture without admixture, mix design was made following recommendation of ACI 211 specification for design a concrete mix of with slump equal to 75 mm and compressive strength equal to 35 MPa. Results of mix design showed the following: water = 216 kg/m^3, cement = 400 kg/m^3, coarse aggregate = 827 kg/m^3, fine aggregate = 851 kg/m^3. In this experimental work, two series of tests were performed, the first series of test was aimed to select the best dosage of each admixture via optimizing compressive strength. The second series of test was performed to assess the compressive strength, modulus of elasticity and complete compressive stress-strain relationship of the optimized mix. Based on past records (Mahmood et al., 2023, Mahmood et al., 2021, Abu-

Bakr et al., 2024), useful grape extract dosages are 0.25%, 0.3%, 0.35% (by cement weight), mulberry extract dosages are 0.25%, 0.3%, 0.35% and pomegranate molasses dosages are 0.25%, 0.3%, 0.35%. The authors had no certain idea about dosage of gum Arabic and cactus extract, and to overcome this problem, there was a need to attempt larger amount of dosages to search for the best one. For gum Arabic, dosages of 0.2% to 0.8% with 0.1% increment were attempted. Past works indicate that cactus extract is added as mixing water replacement, and in this study the replacement was fixed to be 20%, 25%, 30%, 35% and 40%.

To be more precise, it is necessary to calculate the amount of water in the admixture that becomes a part of the mixing water. Based on equations given by Aïtcin (1998), volume (or weight) of the extra water from any admixture is given by

$$V_w = \frac{C\,(\frac{d}{100})(100-s)}{s} \qquad (1)$$

in which

V_w = volume of water, C= cement content in the mixture, d = dosage of admixture by weight of cement, and s = solid content in admixture.

Based on the information given above, water content varied according to the type and dosage of admixture. Since we have no own test data on solid content of pomegranate molasses, the value was taken from past records and found to be 75.6% (Yilmaz et al., 2007). The variations have small effect since the water in the extract is too small as compared with the fixed mixing water (i.e. 216 kg/m^3) as shown in Table 1. Table 1 shows water and admixture contents for all mixtures. For the mix code, C is used for control mix, Ca is for cactus, GA is for gum Arabic, M is for mulberry, G is for grape, P is for pomegranate, and Sp is for superplasticizer, while the number beside the letter is the admixture dosage.

According to the aforementioned discussion and mix details shown in Table 1, there is a total of 22 mixes. To perform the first series test a total of 66 100x200 mm cylinders were cast, cured and tested.

4. Casting concrete, curing and testing

Mixing all concrete mixtures was done in the laboratory simultaneously at an ambient temperature of 25±1^{o}C. Firstly, coarse aggregate at the standard surface dry state was fed to the electrical tilting drum mixer of 0.16 m^3 capacity, followed by the fine aggregate at the standard surface dry state and 25% of mixing water. Except for the case of control mixture, mixing water was contained the natural extract admixture and left to mix for two minutes. Later, cement was fed followed by the remained water and left to mix for another three minutes till a homogeneous mixture was obtained. Casting concrete specimen was done in plastic cylindrical mound in three layers, each layer was vibrated, and later the fresh concrete surface was well leveled. After 24 hrs from casting, the specimen was taken from the mold and put in water tank for curing for 28 days at the ambient temperature of 25±1^{o}C. After curing, the specimens left in the laboratory for 7 days to dry and tested for compressive strength assessment. Before testing, all specimens were capped at the rough top surface according to the requirements of ASTM C617M specification (2016). Each specimen was tested according to ASTM C39/C39M specification (2013) using a

CONTROLS-Italy type testing machine having a maximum capacity of 3000 kN under loading rate condition of 0.25 MPa/sec.

5. Results of first series test and discussion

Table 2 contains results of compressive strength, and Figs. 4 through 6 show normalized compressive strength of different concrete mixtures. Coefficient of variation (COV) is 4.79% for the control mixture without admixture and reduced for the mixtures containing cactus, mulberry and grape extracts but increased for those mixes contained gum Arabic and pomegranate extracts. Any reduction of COV indicating mixture homogeneity enhancement and this, in turn, means better dispersion of cement particles inside the aqueous phase during hydration.

One can observes a compressive strength enhancement because of the natural admixture addition to concrete except for the mixture containing gum Arabic admixture and pomegranate added by 0.35%. Maximum strength enhancement is for the mix contained 0.3% pomegranate extract admixture which is 37.8% and maximum strength loss is for the mix containing 0.2% gum Arabic admixture which is 15.4%. Totally, action of different extract admixtures is good except gum Arabic to enhance compressive strength. It is observed that the performance of pomegranate extract is better than that of all other admixtures even if when added by 0.25% (29.2% strength enhancement). The action of grape extract is good if added by 0.25% since there is a compressive strength enhancement of 25.2%.

It is better herein to show the effect of natural admixtures on compressive strength of concrete tested by the past researchers, to compare with our results. With regard the cactus extract, according to Amaran and Ravi (2016) data, when water is replaced by 10% and 20% cactus extract, there is an improvement in compressive strength of concrete mixes tested at 7, 14 and 28 days, increased with increasing cactus ratio. The strength enhancement is relatively large and reached more than 70%, considerably larger than that obtained in our study. Tests by Aquilina et al. (2018) also showed compressive strength enhancement of mortar at ages of 28 and 90 days, and reduction in 3 days. Higher strength reduction was for concrete mix tested at 28 days contained 60% cactus as water replacement. It will be noted that there was a strength loss of cement paste containing cactus extract even at ages of 28 and 90 days. Consequently, the strength enhancement could be attributed to the improvement of the transition zone between cement paste and aggregate. Other tests by Shanmugavel et al. (2020) indicate a compressive strength enhancement of concrete because of cactus extract tested at 28, 56 and 90 days. Strength enhancement of about 30% was obtained on using 10% cactus extract for concrete tested at 28 days, well larger than that obtained in our study.

With regard gum Arabic, tests by Mbugua et al. (2016) indicate that there is compressive strength loss of cement mortar contained gum Arabic added by 0.3% to 1.1% with 0.1% increment, tested at 2, 7, 28 days. Minimum strength loss was for the mix contained gum Arabic between 0.7% and 0.9% depending of curing age. Consequently, our results are in agreement with the findings of Mbugua et al. (2016). According to data by Elinwa et al. (2018), there is compressive strength increase with increasing gum Arabic dosage in concrete and the best dosage is 0.5% for concrete mixes tested at 3, 7, 28, 60, and 90 days. Maximum strength enhancement was found to be 39.5% for the specimen tested at 7 days.

No appreciable change in compressive strength of concrete because of gum Arabic is observed based on tests by Mouanda et al. (2021) for specimens tested at 7, 14 and 28 days. The source of different responses of concrete against gum Arabic may be due to changing chemical composition of gum Arabic used by different investigators. Changing chemical composition has an effect on hydration process of cement and changing microstructure of the hardened cement paste and also on the interfacial bond between cement paste and aggregate. The characteristics of Osumulite, tobermorite and other minerals in gum Arabic are believed to be factors contributing to the strength enhancement. Tests on gum Arabic sample showed containment of minerals like Sepiolite, Mordenite, and Wollastonite that able to impact the mechanical strength and physical properties of the concrete (Elinwa et al., 2018). According to tests by Mathur et al. (2007), wollastonite mineral if added to concrete as partial substitution of cement improves both flexural and compressive strengths.

According to test data by Abu-Bakr et al. (2024), when grape and pomegranate extracts are added by 0.3% there is compressive strength enhancement of mortar by 23.7%, while on using mulberry extract the enhancement is 19.8%. Current test data indicate higher strength enhancement for the mix containing mulberry and pomegranate extracts but lower strength enhancement on using grape extract. It will be noted that strength enhancement obtained in our study is higher if grape extract is used by 0.25% compared with the data of Abu-Bakr et al. (2024). Further, if one compare our data with those obtained by Mahmood et al. (2021), there is lower strength enhancement (17.5% compared with 21.02%) for the mix containing mulberry extract and higher strength enhancement on using grape extract (25.2% compared with 23.2%).

Mahmood et al. (2023) explained the reason behind compressive strength improvement of concrete because of mulberry extract. Firstly, the strength enhancement could be attributed to the sugar (carbohydrate) content in the natural admixture, knowing that there are records (Aprana et al. 2017) illustrating the positive effect of sugar in concrete. Secondly, the presence of mineral compounds (potassium followed by calcium) helps to improve strength. The potassium mineral can precipitate inside the cement pastes mass, particularly at early ages (3 days), causing segmentation of such pores and enhancing homogeneity leading to compressive strength enhancement. Woldemariam et al., (2014) reported that the extract derived from a plant has chains that react with Ca^{++} to give C-S-H gel. The newly produced gel comes from the reaction of the carboxyl group chains and other chains present in the extract with the Portlandite produced from cement hydration. The produced gel links can fill up the small cavities and micro-cracks produced at the early stage of cement hydration accompanied with strength enhancement. The above reasons of strength enhancement because of mulberry extract may be also valid for concrete containing grape and pomegranate extracts since the chemical composition of the three materials is close to each other with regard the sugar and mineral contents.

Totally, the best dosage is 0.25% for grape extract and equal to 0.3% for both mulberry and pomegranate extracts for best compressive strength enhancement, as one can find from Fig. 6. The above discussion will pave way to select the optimum dosage of natural extract admixture gives maximum compressive strength. First of all, using gum Arabic has no good action on compressive strength and this negative action may reflect on several other concrete properties having strong relation with compressive strength. For cactus extract optimum dosage is 35% as water replacement. Best action of mulberry and pomegranate

extracts is related to using 0.3% and optimum dosage of grape extract is 0.25% all added by cement weight. The determined optimum dosage has a potential when one wants to design a concrete mixture containing natural extract admixture to be good alternative of the currently used chemical water reducing admixture.
Strength enhancement because of cactus extract could be attributed to increasing homogeneity of hardened cement paste structure especially near aggregate particles via improving dispersion of cement particles inside the aqueous phase during hydration. Also, the availability of different useful materials in the admixture could help to improve the pore structure of hardened cement paste especially in the transition zone near aggregate particles. Also, polysaccharides available in the extract influence the strength characteristics of the additive modified concrete while proteins and fats have an impact on the workability and durability of modified concrete (Shanmugavel et al., 2020). The later authors reported that the enhancement of mechanical characteristics of concrete because of cactus extract could be attributed to the effect of polysaccharides present in cactus solution. The additive also acts as an adhesive that produced a solid microstructure of concrete and reduces the shrinkage produced microcracks. For the case of lime mortar, Ravi et al. (2018) attributed compressive strength enhancement because of cactus to filling gap between two consecutive lime particles and enhancing the adhesion, leading to increasing bond strength of the mortar.

6. Second series test program

Based on the determines optimum dosage of each admixture, further tests were performed to investigate the effect of the natural extract admixture on slump of fresh concrete, modulus of elasticity and compressive stress- strain relationship of the hardened concrete. Also, slump of fresh concrete was measured to show workability change because of admixture. From the results of the first series, we have now six mixes with optimum dosage of natural admixture and to compare the action of natural admixture with that of chemical admixture, a concrete mixture containing 0.35% superplasticizer was also investigated. Because of having seven mixes, twenty one 100x200 mm cylinders were cast, cured and tested.

6.1 Slump

Slump was measured on the seven fresh concrete mixes following the procedure steps given by ASTM C 143 specification (2003).

6.2 Compressive stress-strain relationship

The universal testing machine used for compressive strength measurement discussed in the first series tests was used to measure the compressive stress-strain relationship of concrete cylinders. To measure strain, axial shortening was measured during loading concrete via two digital dial gages of an arrangement shown in Fig. 7. Gage length was kept to be 150 mm.

6.3 Modulus of elasticity

From the results of compressive stress-strain relationship, there is a chance to calculate modulus of elasticity of concrete. Modulus of elasticity was calculated from the following equation given by ASTM C469 specification (2003):

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \qquad (2)$$

in which E = chord modulus of elasticity, MPa
S_2 = stress corresponding to 40% of ultimate stress, MPa
S_1 = stress corresponding to longitudinal strain, ε_1, of 50 millionth, MPa, and
ε_2 = longitudinal strain produced by stress S_2.

7. Second series test results and discussion

Table 3 shows results of the second series test represented by slump value, compressive strength, modulus of elasticity and strain corresponding to peak stress. Fig. 9 shows compressive stress-strain relationship for the three specimens made of concrete containing cactus extract admixture, while Fig. 10 shows results of compressive stress-strain relationship for all mixes. Out of the three relationships obtained experimentally, only that one given herein having compressive strength value close to the average value. Discussion of test results in some detail is given below.

One can find a workability enhancement because of superplasticizer by 51.6%, but cactus extract addition to the mix will lead to a slump reduction by 19%. This may be because of the fact that 35% of the mixing water was replaced by this extract which contains a large amount of natural fibers that may affect the flow of freshly mixed concrete. Good action of other natural extracts is observed to enhance workability in which there is more than 111% slump enhancement because of gum Arabic. In fact, there was a collapse slump for the mix containing gum Arabic because slump value was larger than 200 mm. The results of workability enhancement is compatible with that obtained by Afroz et al. (2020). Second better extract with regard slump enhancement is pomegranate extract in which on using there was 104.2% workability enhancement. Grape extract action on slump improvement is good since one can find 87.4% slump enhancement followed by mulberry extract (31.6%). The high variation of slump among different admixtures is well related to the chemical compounds existed in the extract and their relation with the Portland cement particles in the aqueous phase. One can find that the action of the majority of natural extracts is better than that of superplasticizer added to the mix by the same dosage.

As compared with the results of the first series test program, there is some change in the compressive strength values indicating the sensitivity of the natural admixture action on the hydration process during the 28 days which was the age of the specimen at testing. Again, similar to the case of the first series tests, homogeneity of the mixture improves because of the natural admixture represented by the low ratio of COV in the case of compressive strength and modulus of elasticity (except for the mix containing gum Arabic admixture).

Compressive strength enhancement for the mix containing pomegranate extract is 29.9% lower than that of the first series test (37.8%). In the new test program, maximum strength enhancement is for the mix containing cactus extract which is 32.6%, compared with only 13.3% for the other test series. This indicates the sensitivity of cactus extract preparation on the residual strength of concrete. Results of compressive strength enhancement because of cactus extract are in compatible with that observed by Aquilina et al. (2018). For the mix with mulberry extract, the strength enhancement is 29.9% larger than that of other series which is 23.4%. In this series, high strength reduction is observed for the mix containing gum Arabic extract which is 13%. In fact, the residual strength is quite sensitive to the dosage and properties of the gum Arabic admixture.

Further, there is lower strength enhancement for the mix containing grape extract which is 19.5% compared with the other test series. Totally, from the two test series one can find a good action of different extracts on the compressive strength enhancement except gum Arabic. Results of Fig. 8 show us that the performance of cactus, pomegranate, mulberry, grape extracts is better than that of superplasticizer since the strength enhancement because of the chemical admixture is only 8.7%.

Results of Fig. 8 showed that there is modulus of elasticity enhancement because of pomegranate extract equal to 8.3% slightly larger than that because of superplasticizer addition to the mix. Using other types of extracts will lead to the elastic modulus reduction by a ratio between 2.1% and 22.7% and the worse condition is on using gum Arabic. In general, because of using natural extracts except mulberry, there is a strain corresponding to peak compressive strength enhancement by a ratio between 10.3% and 22%. The value for concrete mixture with superplasticizer is higher, but there is a strain reduction for the mix containing mulberry extract by 6.9%.

Results of Fig. 10 indicate that the shape of compressive stress-strain relationship is different for concrete containing gum Arabic in which there is a lower slope of both ascending and descending branches of the curve. Ascending branch of the relationship for other concretes is not differing widely but the descending branch tends to be different for some mixes.

Fig. 11 shows different cylinder specimens after testing. Concrete cylinder for concrete containing pomegranate extract was more damaged by compression while that of concrete containing cactus subjected to lesser damage and this could be attributed to the existence of a large amount of natural fibers in cactus.

8. Conclusion

Natural extract admixtures has a promised future to be used as an alternative of chemical admixtures for concrete. These materials could be prepared using simple techniques without the need for advanced chemical treatments and consequently could be considered as a clean product. In this experiment, action of different extracts on some important properties of concrete has been examined. Outcomes of the study is interested and pave way for producing an environmental-friendly concrete based on natural resources instead of the currently used chemical admixtures. Further, the following conclusions are drawn:

1- Using natural extract admixture is a good alternative of the currently used chemical admixture because of useful impacts on both fresh and hardened concretes. Improvements in workability and compressive strength because of using natural admixtures is better than those occurred because of superplasticizer, both added by the same dosage.

2- On using gum Arabic, there is a high workability enhancement by more than 111% but using this admixture will lead to a compressive strength loss by 13%. Workability of concrete mixtures containing grape and pomegranate extracts was found to be higher than that of the mix containing superplasticizer but lower workability of the mixes containing mulberry and cactus extracts was observed.

3- Good compressive strength enhancement for concrete containing cactus and pomegranate admixtures is observed by a ratio between 29.9% and 32.6% compared with control mixture without admixture.
4- There is modulus of elasticity enhancement because of pomegranate extract equal to 8.3%, but using other extracts in concrete will lead to the elastic modulus reduction by a ratio between 2.1% and 22.7%. Using natural extracts except mulberry, there is a strain corresponding to peak compressive strength enhancement by a ratio between 10.3% and 22%.
5- Totally, pomegranate extract is the best one among all natural admixtures since on using there is both workability and compressive strength enhancements.
6- Overall, the results of this study are interested and paves the way for further research and even practical applications. However, this work was carried out on a single control mixture with a design strength of 35 MPa and 95 mm slump workability. There is a need for further research on other concrete mixtures of different strength and workability.

References

Abu-Bakr, M., Mahmood, H.F., Mohammed, A.A., Ahmed, S.A. (2024). “Evaluation of mechanical properties and shear-bond strength of mortar containing natural extract admixture”, Construction and Building Materials, 418, 135377, https://doi.org/10.1016/j.conbuildmat.2024.135377

Acharya, D. P., Gyawali, T. R. (2024). “Investigation of the performance of natural molasses on physical and mechanical properties of cement mortar”, Ain Shams Engineering Journal, 15(1), 102355, https://doi.org/10.1016/j.asej.2023.102355

ACI Committee 318. (2025). “Building code requirements for structural concrete", American Concrete Institute, Farmington Hills, First Printing.

Afroz, S., Manzur, T., Hossain, K. M. A. (2020). “Arrowroot as bio-admixture for performance enhancement of concrete”, Journal of Building Engineering, 30, 101313, https://doi.org/10.1016/j.jobe.2020.101313

Ahmed JK, Abdulrahman PI, Atmaca N, Khoshnaw GJ (2024) High-performance engineered geopolymer composites: A sustainable approach using recycled brick waste, J Appl Polym Sci. 2024;e56478. https://doi.org/10.1002/app.56478

Aïtcin, P.C. (1998). “High Performance Concrete”, E. & FN Spon, New York.

Akar, C., Canbaz, M. (2016). “Effect of molasses as an admixture on concrete durability”, Journal of Cleaner Production, 112, 2374–2380. https://doi.org/10.1016/j.jclepro.2015.09.081

Amaran, R., Ravi, R. (2016). “Effect of cactus on the rheological properties of cement”, Int. J. Chem. Sci, 14(S1), 203–210.

Aprana, B.D., Acharya, V.T., Keerthi, G.B.S. (2017). "Effect of sugar on setting-time and compressive strength of concrete", Proceedings of ICGCSC Conference: 335–337.

Aquilina, A., Borg, R. P., Buhagiar, J. (2018). “The application of Natural Organic Additives in Concrete: Opuntia ficus-indica”, IOP Conference Series: Materials Science and Engineering, 442, 012016. https://doi.org/10.1088/1757-899x/442/1/012016

ASTM C39/C39M-21 (2021). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens", ASTM International, West Conshohocken.

ASTM C136/C136M. (2019). "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", ASTM International,, West Conshohocken, PA, USA, 2019.

ASTM Designation C143 (2020). “Standard Test Method for Slump of Hydraulic-Cement Concrete”, ASTM International, West Conshohocken, PA, USA.

ASTM Designation C469-22 (2022). “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression”, ASTM International, West Conshohocken, PA, USA.

ASTM Designation C617/C617M (2023). “Standard Practice for Capping Cylindrical Concrete Specimens”, Annual Book of ASTM Standard.

Babu, T. R., & Neeraja, D. (2017). A experimental study of natural admixture effect on conventional concrete and high volume class F flyash blended concrete. Case studies in construction materials, 6, 43-62, https://doi.org/10.1016/j.cscm.2016.09.003

BS 882 (1992). “Specification for aggregates from natural sources for concrete”, BSi Standards.

Chandra, S., Aavik, J. (1983). “Influence of black gram (natural organic material) addition as admixture in cement mortar and concrete”, Cement and Concrete Research, 13, 423-430, https://doi.org/10.1016/0008-8846(83)90043-1

Chandra, S., Eklund, L., Villarreal, R. R. (1998). “Use of Cactus in Mortars and Concrete”, Cement and Concrete Research, 28(1), 41–51. https://doi.org/10.1016/s0008-8846(97)00254-8

Dakas, A., Agboju, S., Enjugu, A. (2017). “The Effect of Gum Arabic on Sisal Fibre-Reinforced Concrete: Alternative Material for Prevention of Balling”, CARD International Journal of Engineering and Emerging Scientific Discovery, 2(2), 2536–7269.

Elinwa, A. U., Abdulbasir, G., Abdulkadir, G. (2018). “Gum Arabic as an admixture for cement concrete production”, Construction and Building Materials, 176, 201–212. https://doi.org/10.1016/j.conbuildmat.2018.04.160

Hazarika, A., Hazarika, I., Gogoi, M., Bora, S. S., Borah, R. R., Goutam, P. J., Saikia, N. (2018). “Use of a plant based polymeric material as a low cost chemical admixture in cement mortar and concrete preparations”, Journal of Building Engineering, 15, 194–202, https://doi.org/10.1016/j.jobe.2017.11.017

Hazarika, A., Hazarika, I., Saikia, N. (2016). “The effect of a plant based polymeric material on the fresh and hardened states properties of cement mortar”, in: Proceedings of the 1st International Conference on Civil Engineering for Sustainable Development-Opportunities and Challenges At: Guwahati, India, Volume: I

Kassa, Y. (2019). “Application of cane molasses as concrete retarder admixture”, SN Applied Sciences, 1(12). https://doi.org/10.1007/s42452-019-1608-8

Mbugua, R., Salim, R., Ndambuki, J. (2016). “Effect of Gum Arabic Karroo as a water-reducing admixture in cement mortar”, Case Studies in Construction Materials, 5, 100–111. https://doi.org/10.1016/j.cscm.2016.09.002

Mahmood, H.F., Dabbagh, H., Mohammed, A.A. (2021). “Comparative study on using chemical and natural admixtures (grape and mulberry extracts) for concrete”, Case Studies in Construction Materials, 15, e00699, https://doi.org/10.1016/j.cscm.2021.e00699

Mahmood, H.F., Dabbagh, H., Mohammed, A.A. (2023a). "Performance of Grape Extract Addition as an Admixture in Concrete Construction", Civil Engineering Infrastructures Journal, 56 (2), 347-364, DOI: 10.22059/CEIJ.2023.345306.1855.

Mahmood, H.F., Dabbagh, H., Mohammed, A.A. (2023b). “Improvement of mechanical and physical properties of normal concrete using mulberry extract as an admixture”, Asian Journal of Civil Engineering, 24, 1309-1321, https://doi.org/10.1007/s42107-023-00570-z, https://doi.org/10.1007/s42107-023-00570-z

Mathur, R., Misra, A.K., Goel, P. (2007). "Influence of wollastonite on mechanical properties of concrete", Journal of Scientific & Industrial Research, 66, 1029-1034.

Mohammed, A.A., Mohammed, A.S., Ahmed, H.U., Faraj, R.H. (2024). “Evaluation of concrete properties using prosopis farcta extract admixture”, Innovative Infrastructure Solutions, 9:272, https://doi.org/10.1007/s41062-024-01589-0

Meron, E. (2019). “Effect of molasses on properties of C-25 concrete as admixture”, MSc thesis, Jimma University, https://repository.ju.edu.et//handle/123456789/5648

Mouanda, G. F. M., Abuodha, S.O., Thuo, J.N. (2021). “Structural Performance of Concrete mixed with Gum Arabic as a Biopolymer Admixture and Calcined Kaolin as a Partial Replacement for Cement”, SSRG International Journal of Civil Engineering, 8(11), 41–47, DOI:10.14445/23488352/IJCE-V8I11P106

Ravi, R., Rajesh, M., Thirumalini, S. (2018). " Mechanical and Physical Properties of Natural Additive Dispersed Lime", Journal of Building Engineering, 15:70-77 https://doi.org/10.1016/j.jobe.2017.10.009

Reddy, A. (2023). “Influence of Molasses as an Admixture on Concrete”, Erudite Journal of Engineering Tecnology and Management Sciences (EJETMS), 3(2), 1–3.

Shanmugavel, D., Selvaraj, T., Ramadoss, R., Raneri, S. (2020). “Interaction of a viscous biopolymer from cactus extract with cement paste to produce sustainable concrete”, Construction and Building Materials, 257, 119585. https://doi.org/10.1016/j.conbuildmat.2020.119585

Thirumalini, P., Sekar, S.K. (2013). “Review on Herbs used as Admixture in Lime Mortar used in Ancient Structures”, Indian J. of Appl. Res. 3(8), 295-298.

Woldemariam, A. M., Oyawa, W. O., Abuodha, S. O. (2014). “Cypress tree extract as an eco-friendly admixture in concrete”, International Journal of Civil Engineering and Technology (IJCIET), 5(6), 25–36.

Woldemariam, A.M., Walter, W.O., Abuodha, S.O. (2015). “The Use of Plant Extract as Shrinkage Reducing Admixture (SRA) to Reduce Early Age Shrinkage and Cracking on Cement Mortar,” International Journal of Innovation and Scientific Research, 13 (1), 136–144.

Yildirim, H., Altun, B. (2012). “Usage of molasses in concrete as a water reducing and retarding admixture”, Indian Journal of Engineering & Materials Sciences, 19 (6), 421–426.

Yilmaz, Y., Çelik, I., Isik, F. (2007)." Mineral composition and total phenolic content of pomegranate molasses," Journal of Food, Agriculture & Environment, 5 (3&4), 102-104. 2007

Table 1 Content of water and admixture (kg/m^3)

Mix code	Water	Admixture	Mix code	Water	Admixture	Mix code	Water	Admixture
MCa-20	172.8	43.2	MGA-0.2	216.4	0.8	MM-0.25	216.61	1.0
MCa-25	162.0	54.0	MGA-0.3	216.6	1.2	MM-0.30	216.73	1.2
MCa-30	151.2	64.8	MGA-0.4	216.8	1.6	MM-0.35	216.86	1.4
MCa-35	140.4	75.6	MGA-0.5	217.0	2.0	MG-0.25	216.70	1.0
MCa-40	129.6	86.4	MGA-0.6	217.2	2.4	MG-0.30	216.84	1.2
			MGA-0.7	217.4	2.8	MG-0.35	216.98	1.4
			MGA-0.8	217.6	3.2	MP-0.25	216.32	1.0
						MP-0.30	216.39	1.2
						MP-0.35	216.45	1.4

M is mix, C is control mix, Ca is cactus, GA is gum Arabic, M is mulberry, G is grape, P is pomegranate, Sp is superplasticizer. The number beside the letter is the admixture dosage.

Table 2 Compressive strength of concrete containing different extract admixtures

Specimen code	Compressive strength (MPa)	COV (%)
MC	38.01	4.79
MCa-20	38.91	2.69
MCa-25	39.61	2.74
MCa-30	39.17	2.71
MCa-35	43.08	2.98
MCa-40	40.58	2.81
MGA-0.2	32.14	6.21
MGA-0.3	35.73	1.62
MGA-0.4	36.14	11.32
MGA-0.5	36.45	9.91
MGA-0.6	35.44	11.47
MGA-0.7	35.37	8.56
MGA-0.8	36.87	7.67
MM-0.25	43.73	3.62
MM-0.3	46.90	1.67
MM-0.35	44.66	1.65
MG-0.25	47.59	2.53
MG-0.3	45.48	2.40
MG-0.35	43.84	4.46
MP-0.25	49.12	7.26
MP-0.3	52.39	4.87
MP-0.35	34.51	22.23

Table 3 Results of second series test

Mix ID	Slump (mm)	f_c' (MPa)		E_c (GPa)		ε_o	
		Mean	S_D	Mean	S_D	Mean	S_D
MC	95	36.08	2.47	30064	10229	0.002068	0.000268
MGA	Collapse (>200)	31.40	1.30	23230	11724	0.002436	0.000752
MCa	77	47.83	0.88	26762	3196	0.002281	0.000367
MSp	144	39.23	2.56	32366	2231	0.002648	0.000810
MM	125	46.65	1.02	27245	3725	0.001926	0.119200
MG	178	43.10	1.62	29425	5857	0.002522	0.000613
MP	194	46.86	1.51	32570	9954	0.002363	0.000452

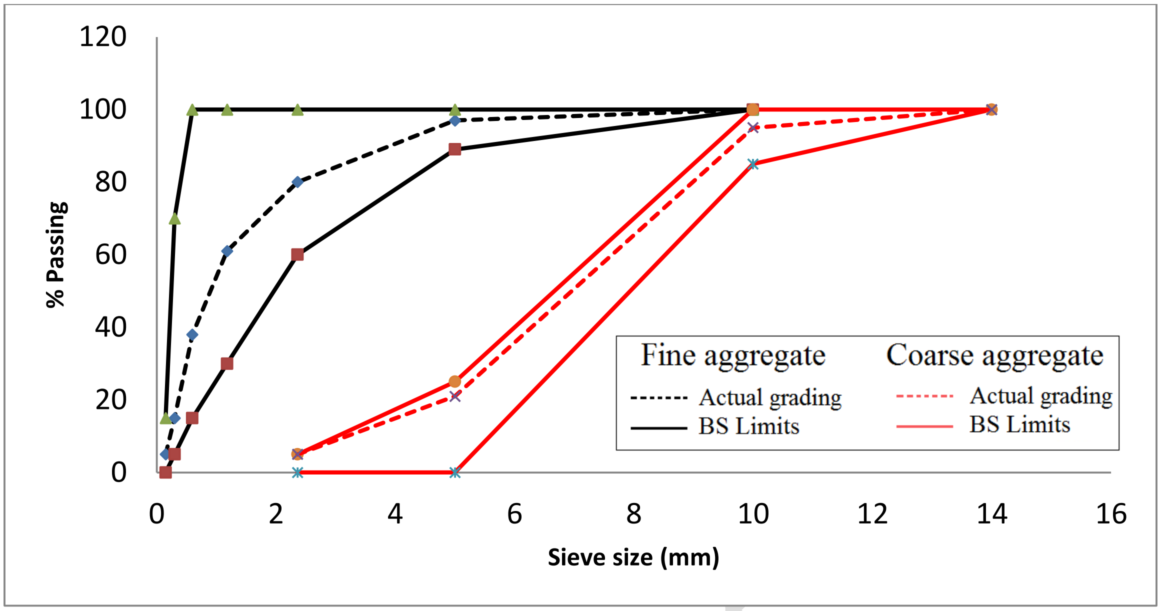
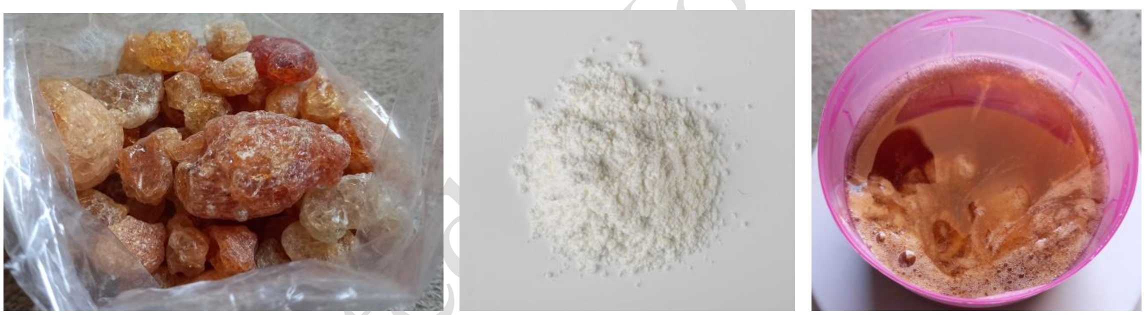


Fig.1 Particle size distribution of fine and coarse aggregates and ASTM C33 specification limits



(a) (b) (c)

Fig. 2 Gum Arabic: (a) actual, (b) after grinding, (c) extract

(a) (b)

(c) (d)

Fig. 3 Cactus extract preparation: (a) Pant, (b) cutting leaves, (c) pellet preparation, (d) extract

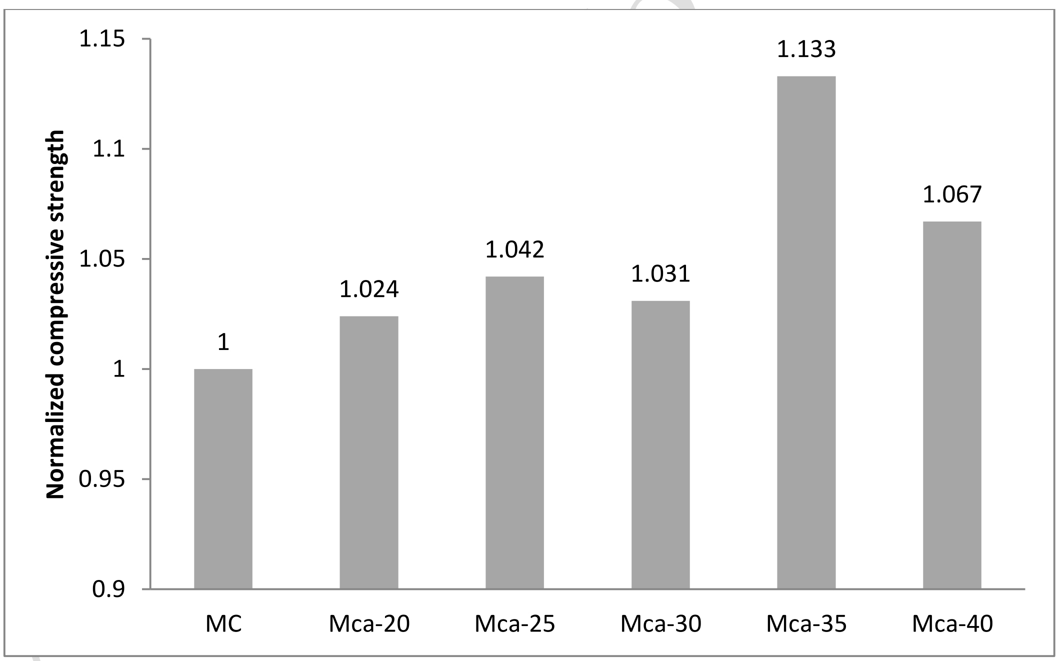


Fig. 4 Normalized compressive strength of concrete mixture containing cactus extract admixture

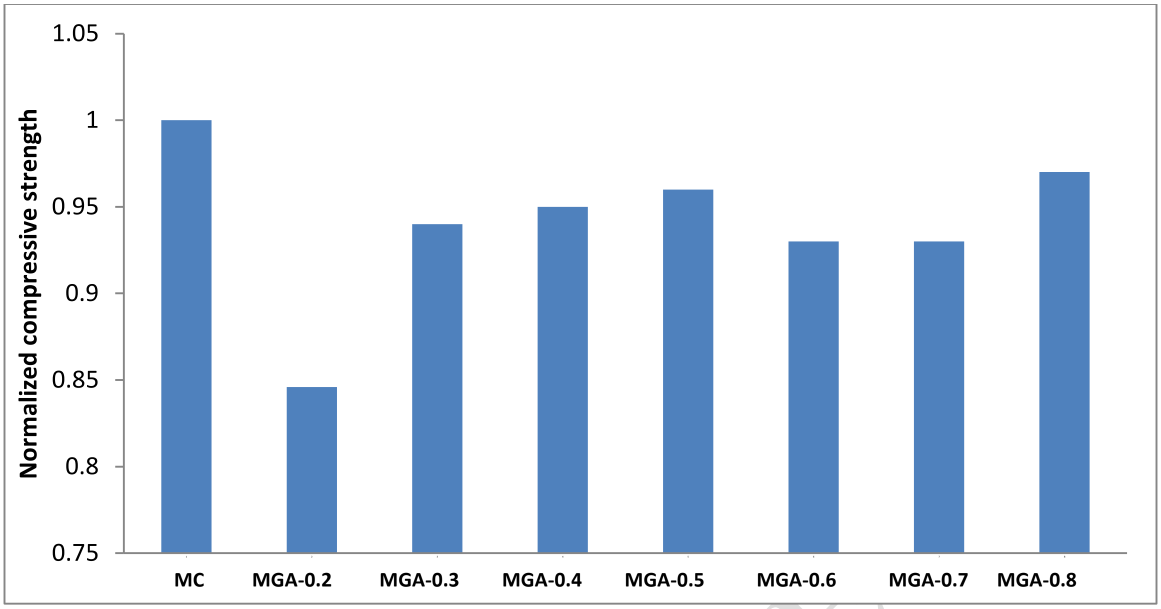


Fig. 5 Normalized compressive strength of concrete mixture containing gum Arabic admixture

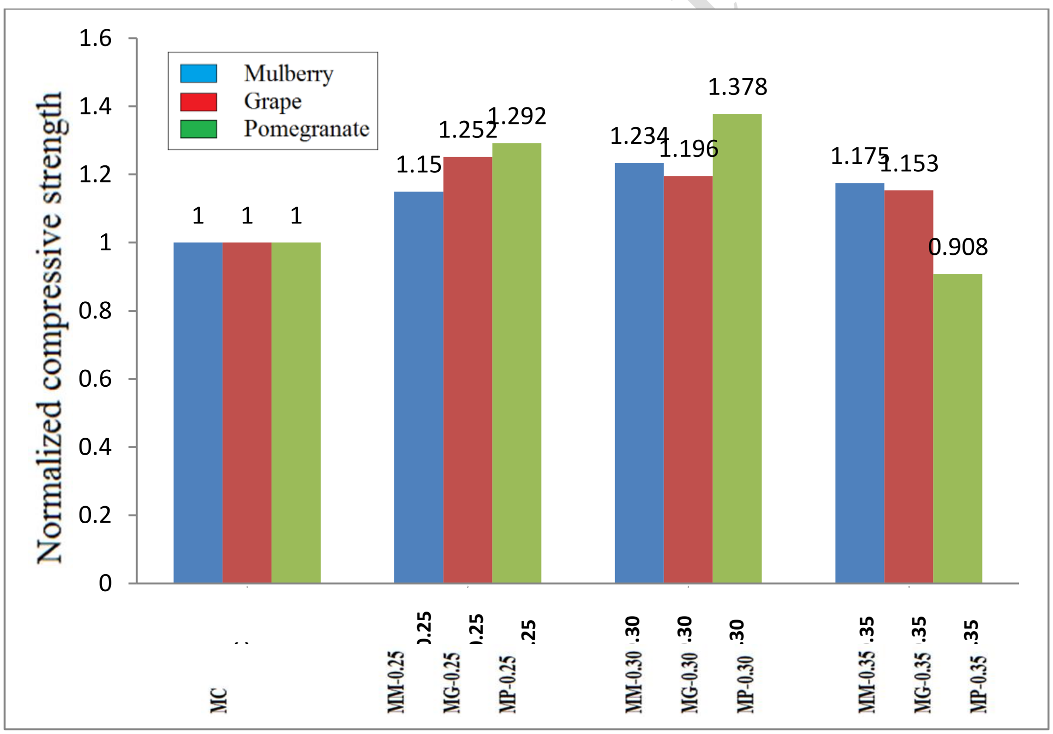


Fig. 6 Normalized compressive strength of concrete mixture containing, mulberry, grape and pomegranate admixtures


Fig. 7 Test procedure for measuring compressive stress-strain relationship

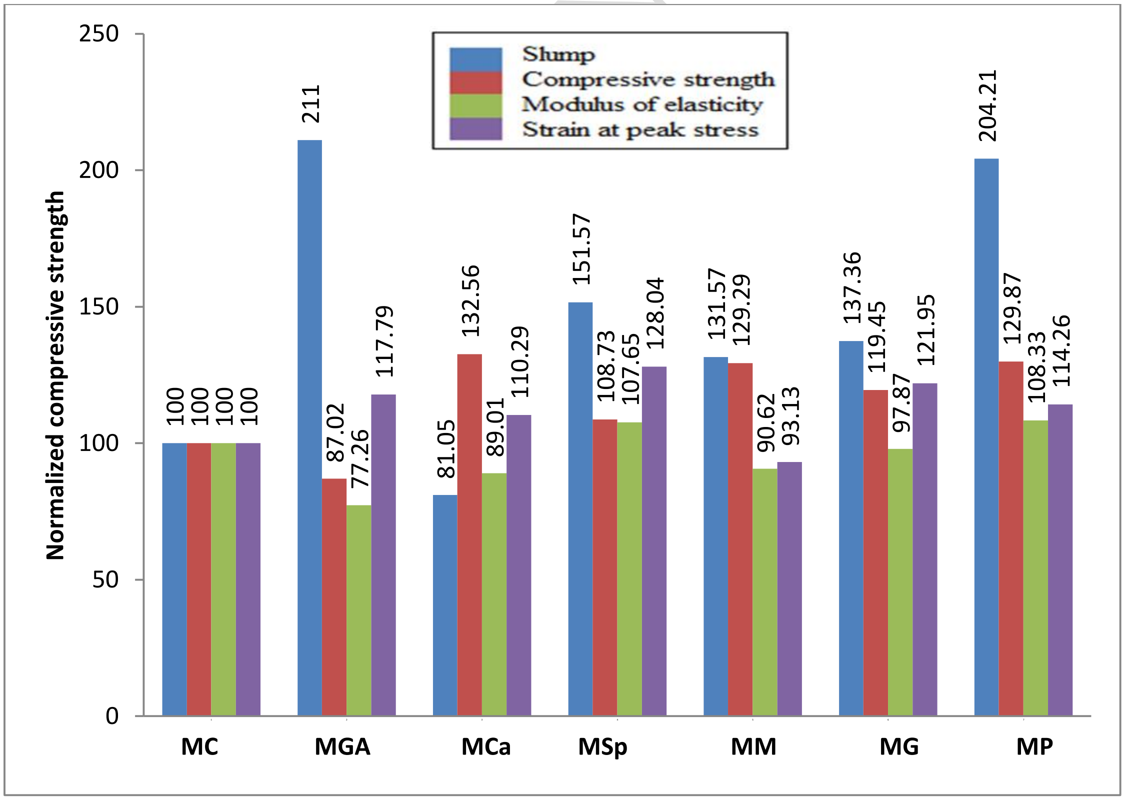


Fig. 8 Compressive strength, modulus of elasticity and strain corresponding to peak stress (Percentage of control mix)

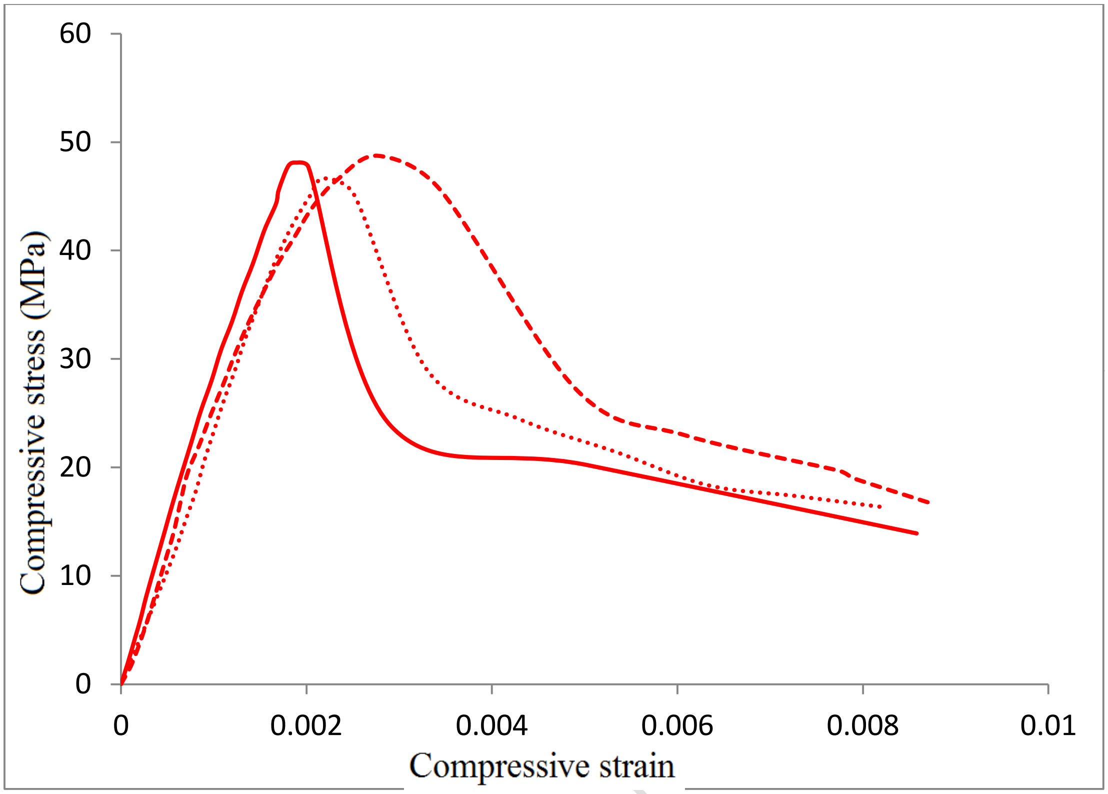


Fig. 9 Compressive stress- strain relationship for specimens made of concrete containing cactus extract

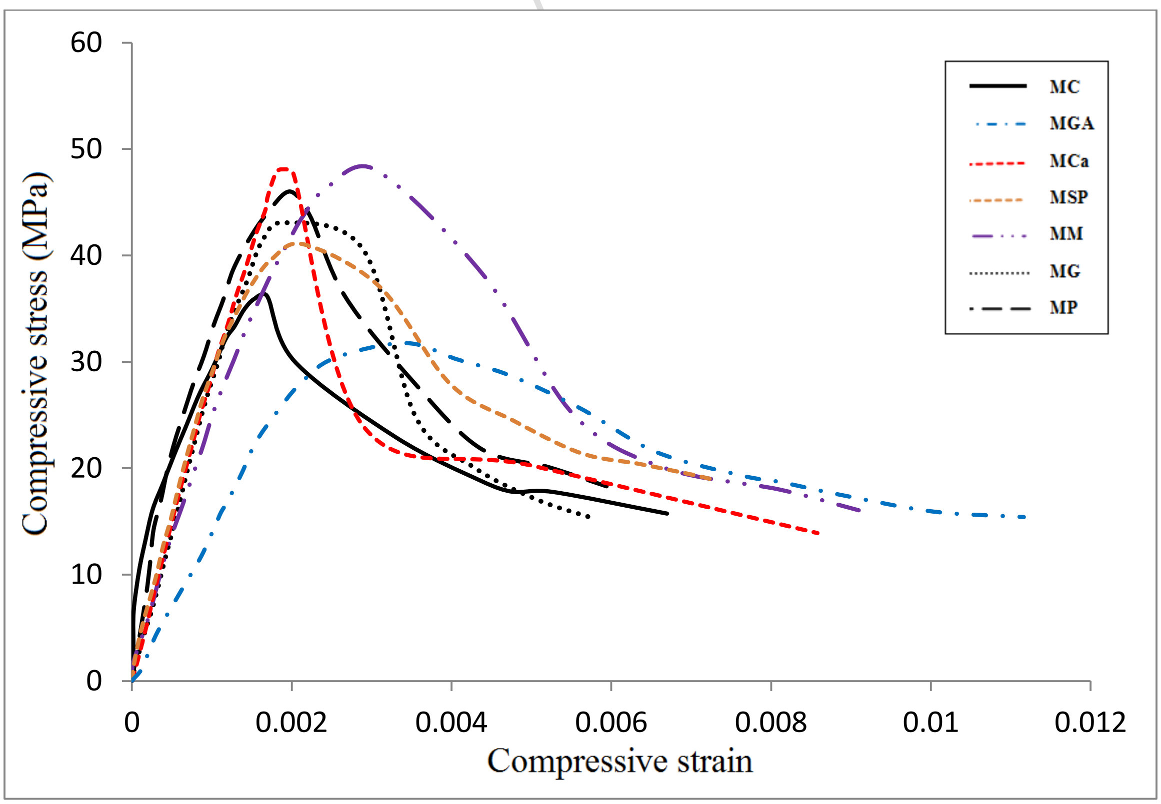


Fig. 10 Compressive stress- strain relationship of different concrete mixes

MC MGA MCa MSp MM MG MP

Fig. 11 View of failed specimens