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FACULTY OF ENGINEERING, CAIRO UNIVERSITY

EARLY AND LATE STRENGTH OF MAGNETICALLY CURED CONCRETE

H. I. AHMED[1]

ABSTRACT

This research is an attempt to find an alternative approach to increase gain rate of concrete early strength by exposing curing water to a magnetic field. Tap water-submerged curing (TWSC) and magnetic water-submerged curing (MWSC) regimes were considered. Four exposure periods (6, 12, 36, and 48 hours) to magnetic field of strength 1.4 Tesla were adopted. Compressive strength, split tensile strength, de-sorption, thermo-gravimetric analysis (TGA) and scanning electron microscopy (SEM) approaches were conducted through this research. MWSC showed superior mechanical and microstructure characteristics especially in early ages. Specimens cured in magnetic water for 48 hours showed the highest increase in 3-days and 28-days compressive strength (50% and 7%, respectively), reduction in 3-days and 28-days free lime content (55% and 8%) and 28-days capillary porosity (9%) compared to specimens cured in tap water (TWSC). SEM results supported the mechanical observations, where magnetically treated concrete revealed a better morphology. These results confirm the ability of MWSC to improve the early age mechanical behavior of concrete. Future studies are needed in the field of MWSC in terms of magnet strength and magnetic processing time.

KEYWORDS: Curing; early age; magnetic treatment; compressive strength; capillary porosity.

1. INTRODUCTION

Increasing the rate of early strength development of concrete is a major requirement in many applications such as prestressed concrete, precast concrete, cold weather concreting, and repair works. There are several ways to obtain high early strength, including modifying the mineral composition of cement, adding accelerating admixtures, the use of elevated curing temperature which are achieved through

[1] Assistant Professor of Strength and Properties of Materials, Civil Eng. Dept. Faculty of Eng., Beni-Suef University.

various means [1].The rates of cement hydration can be increased by adding accelerating admixtures to the cement matrix. These admixtures increase gain rate of concrete early strength. The main action of these accelerators occurs in the plastic state of concrete [2]. Some accelerators act as either set accelerator or hardening accelerator, while several accelerate both setting and hardening [3].

Heating procedures on concrete is one of the most commonly methods used to improve early strength [4]. This approach is based on accelerating the hydration reactions. Some authors found that, at early ages, concrete exposed to high temperatures has higher early-age mechanical strengths and lower later-age strengths than concrete subjected to normal temperatures [5].

Curing is essential to ensure the continuity of the hydration process by maintaining moisture content and temperature within the concrete for an appropriate period. A number of curing techniques can be processed depending on the various factors considered in site or due to the construction method. They range from the most popular water-submerged curing to wet sand, water-spray curing, polythene membrane sealing and steam curing (autoclaving). Water-submerged curing has been done in most of the previous research using tap water [6].

Recently, the effect of magnetic-water technology on concrete properties has attracted the attention of many authors [7-10]. The first machine of magnetic water treatment was designed in 1945. This machine has a strong magnet which is the source of magnetic energy production. This magnet is installed in a small tube to produce a magnetic field reaching a high rate of approximately 6500 Gauss. Magnetized water means passing water through a magnetic tube [11]. Some authors reported that, in a magnetic field, water clusters are transformed into single molecules or smaller clusters, therefore, the activity of water molecules is improved [10]. Structures of (a) tap water molecule clusters and (b) magnetic water molecule clusters are shown in Fig. 1.

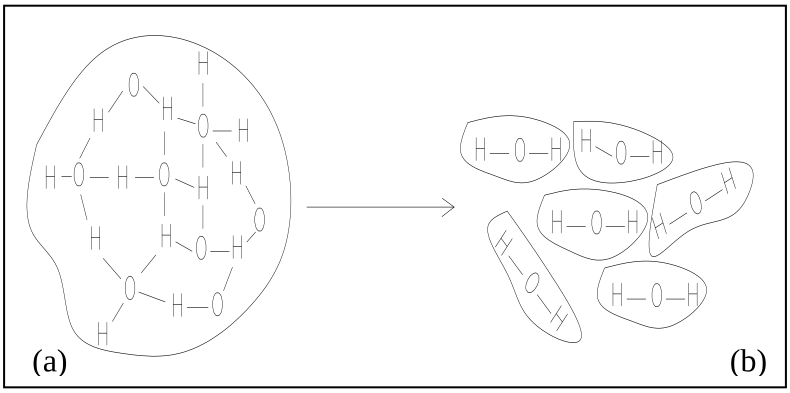

Fig. 1. Structure of (a) tap water molecule clusters and (b) magnetic water molecule clusters.

1.1 Research Significance

This paper presents a new technique to improve the early age mechanical behavior of concrete by exposing curing water to a magnetic field of strength 1.4 Tesla. The specific objectives were as follows:

1. To determine the feasibility of using magnetic water-submerged curing (MWSC) method to improve the early and late strength of concrete.
2. To clarify the effect of magnetic processing of curing water on the microstructure of concrete in terms of capillary porosity and free lime contents.

2. EXPERIMENTAL

2.1 Materials and Mix Proportions

Local CEM I class (42.5 N) and silica fume were utilized throughout the work. Chemical and physical properties of CEM I and SF are presented in Table 1. Clean natural sand with a specific gravity of 2.65 and a fineness modulus of 2.75 and crushed stone with a maximum particle size of 12.5 mm were used. A polycarboxylate superplasticizer (SP) was incorporated into all concrete mixtures. A magnetizer of 1.4 Tesla was purchased from Delta Water Company, Egypt to produce magnetized water. Concrete mixes were batched using water to cement ratio of 0.4. The concrete constituent materials were mixed using a concrete rotating drum mixer with a capacity of 0.125 m^3 for 2 minutes. CEM I pastes were prepared using water-cement ratio of 0.4. Circular CEM I paste discs of thickness 5 mm and 50 mm diameter were prepared for both de-sorption and TGA tests. Mix proportions of concrete mixture are given in Table 2.

Cubes of size 150x150x150 mm and cylinders of size 150x300 mm were used for compressive strength and split tensile strength tests, respectively. Control specimens were cured in tap water at 25°C for 3, 7, and 28 days. For magnetic water-submerged curing regime, concrete specimens were cured in magnetic water reservoir for 6, 12, 36, and 48 hours. Magnetic water was changed every 3 hours. After the end of the magnetic processing, specimens were then submerged in tap water until the ages of testing (3, 7, and 28 days).

Table 1. Chemical analysis and surface areas of CEM I and SF.

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI	Fineness, m^2/g
CEM I	21.2	4.53	3.61	61.6	2.38	0.36	0.22	2.8	1.98	0.3
SF	96.1	0.5	0.71	0.22	0.47	0.32	0.48	0.1	2.5	2

Table 2. Mixture proportions for studying mechanical and microstructure characteristics of CEM I concrete.

OPC (kg)	SF (kg)	Water (kg)	W/C ratio	Aggregate (kg)		S.P. (%)
				Coarse	Fine	
422.5	22.5	180	0.4	1050	720	1

2.2 Test Technique and Procedure

All mechanical tests were performed using an ELE machine with maximum load of 2000 kN. The microstructure of concrete was investigated using scanning electron microscopy “SEM” analysis. SEM Model Quanta 250 FEG “Field Emission Gun” was used thought the work. Capillary porosity and free lime were investigated using de-sorption and TGA approaches, respectively. Full details of technique and procedures are described in [12-17].

3. RESULTS AND DISCUSSION

3.1 Compressive and Split Tensile Strength

The compressive strength results of control specimens (cured in tap water) and those cured in magnetic water for 6, 12, 36, and 48 hours are illustrated in Fig. 2. It is clear that, at all ages, the increase in the magnetic processing time increases the compressive strength of concrete. For all ages, the highest compressive strength was obtained from specimens cured in magnetic water for 48 hours. The improvement in the compressive strength may be attributed to the fact that, magnetic treatment of curing water increases surface area, activity and hence diffusivity of water molecules. The higher activity of curing water increases the rates of cement hydration and pozzolanic reaction. Hence, hydration can be done more efficiently which in turn improves concrete strength [8]. Moreover, it is obvious from Fig. 2 that, for all magnetic processing times, the increase in the compressive strength is more obvious in early ages than late age. The increase in the 3-days compressive strength of specimens cured in magnetic water for 6, 12, 36, 48 hours were approximately 15, 25, 35, and 50%, respectively, compared to reference specimens (cured with tap water). These values were 5, 10, 13, and 16% for 7-days compressive strength and 2, 3, 5, and 7% for 28-days compressive strength.

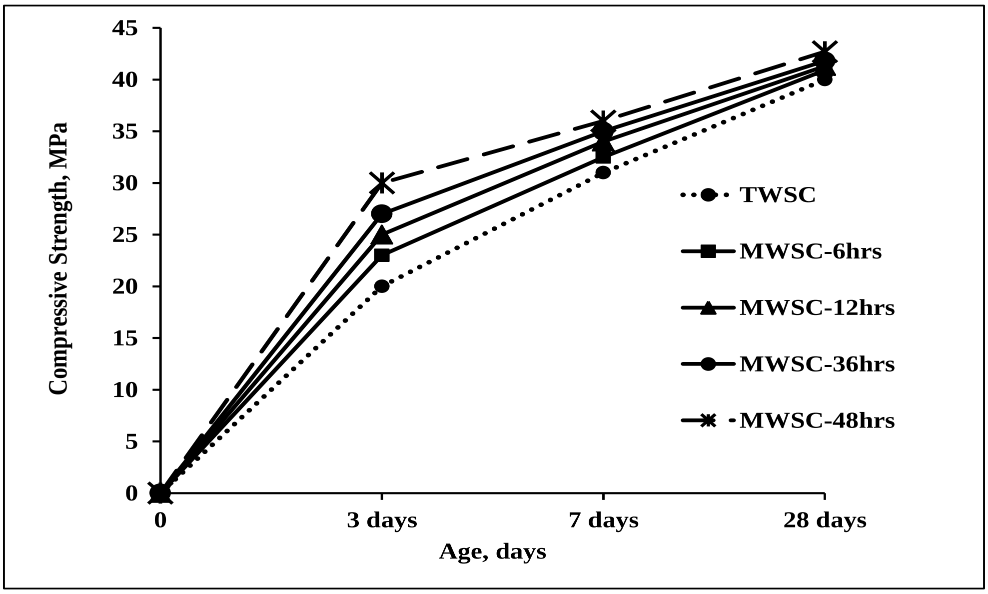

Fig. 2. Effect of magnetic processing of curing water on the early and late compressive strength of concrete.

On the other hand, the effect of magnetic treatment of curing water on the early and late tensile strength is illustrated in Fig. 3. It can be seen that, at all ages, the increase in the period of magnetic processing from 6 hours to 48 hours increases the split tensile strength of concrete when compared to reference specimen (cured in tap water). For all ages, the highest tensile strength was obtained from specimens cured in magnetic water for 48 hours. The improvement in the tensile strength of magnetically treated concrete can be attributed to the higher diffusivity of magnetic water into cement matrix compared to tap water. This increases the hydration products which is helpful to improve microstructure of concrete and hence increase tensile strength. The amount of increase in the 3-days tensile strength of specimens cured in magnetic water for 6, 12, 36, 48 hours reaches about 15, 25, 33, and 45%, respectively, when compared to reference specimens (cured with tap water). These values were 5, 10, 13, and 15% for 7-days tensile strength and 2, 4, 6, and 7% for 28-days tensile strength.

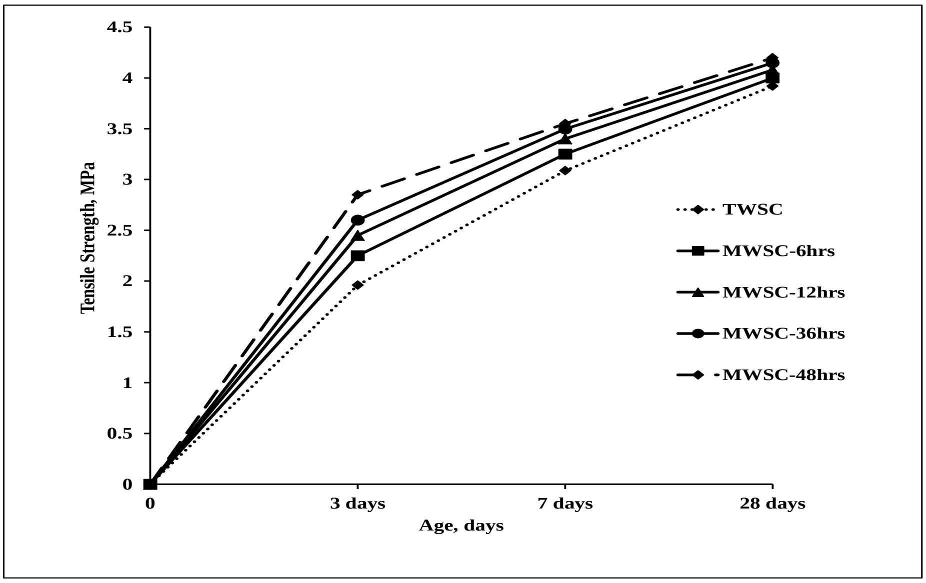

Fig. 3. Effect of magnetic processing of curing water on the early and late tensile strength of concrete.

3.2 Microstructure of CEM I Matrix

3.2.1 Free lime content

The free lime content is represented as a function of magnetic processing and curing times in Fig. 4. As shown, free lime content decreases with curing time for all specimens due to the pozzolanic effect of silica fume. The amount of free lime decreases with increasing magnetic processing time. This reduction was very obvious in early ages than later age and can be attributed to the fact that the higher activity of magnetic water is helpful to accelerate both cement hydration and pozzolanic reaction. The decrease in the 3days-free lime content of specimens cured in magnetic water for 6, 12, 36, 48 hours were approximately 20, 34, 45, and 55%, respectively, compared to reference specimens (TWSC). These values were 9, 18, 42, and 50% for 7-days curing age and 2, 7, 6, and 8% for 28-days curing age.

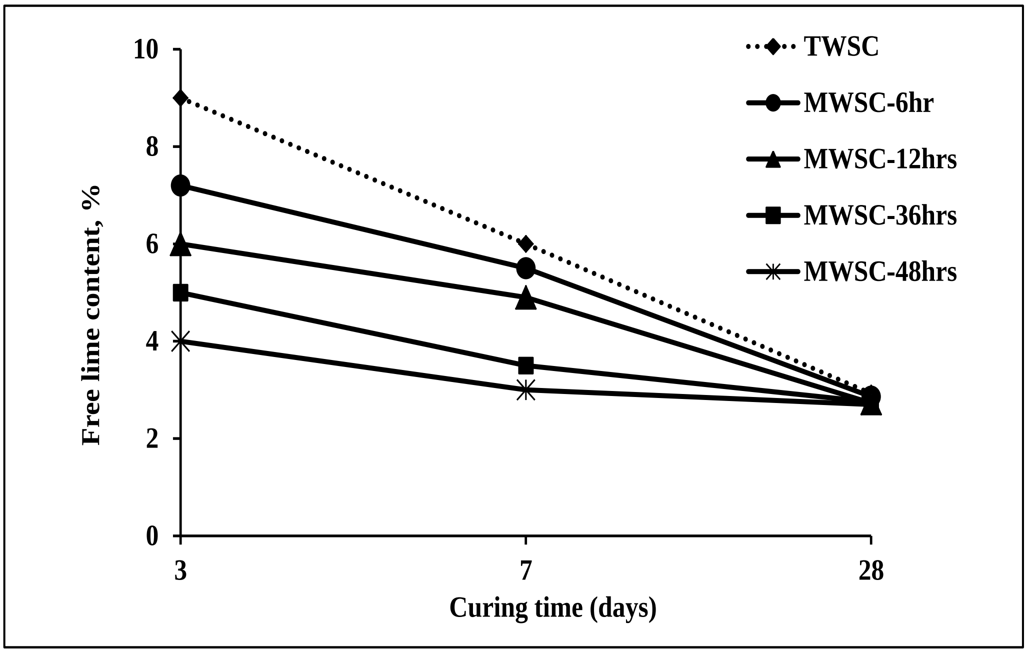

Fig. 4. Free lime content of hardened cement pastes cured up to 28 days and exposed to magnetic field for 6, 12, 36, and 48 hours.

3.2.2 Capillary porosity

The effect of magnetic treatment of curing water on the 28-days capillary porosity of reference CEM I paste specimen (cured in tap water) and magnetically treated specimens is shown in Fig. 5. It can be seen that, increasing the magnetic processing time led to a significant decrease in the capillary porosity. The decrease in the 28-days capillary porosity of specimens cured in magnetic water for 6, 12, 36, and 48 hours reaches approximately 3, 4, 8, and 9%, respectively compared to reference specimen (cured in tap water). This decrease in capillary porosity may be attributed to the ability of magnetic water to increase the rates of cement hydration and pozzolanic reactions and therefore denser concrete will be produced. The capillary porosity results agree with that obtained from SEM, where a better morphology of magnetically treated concrete was observed.

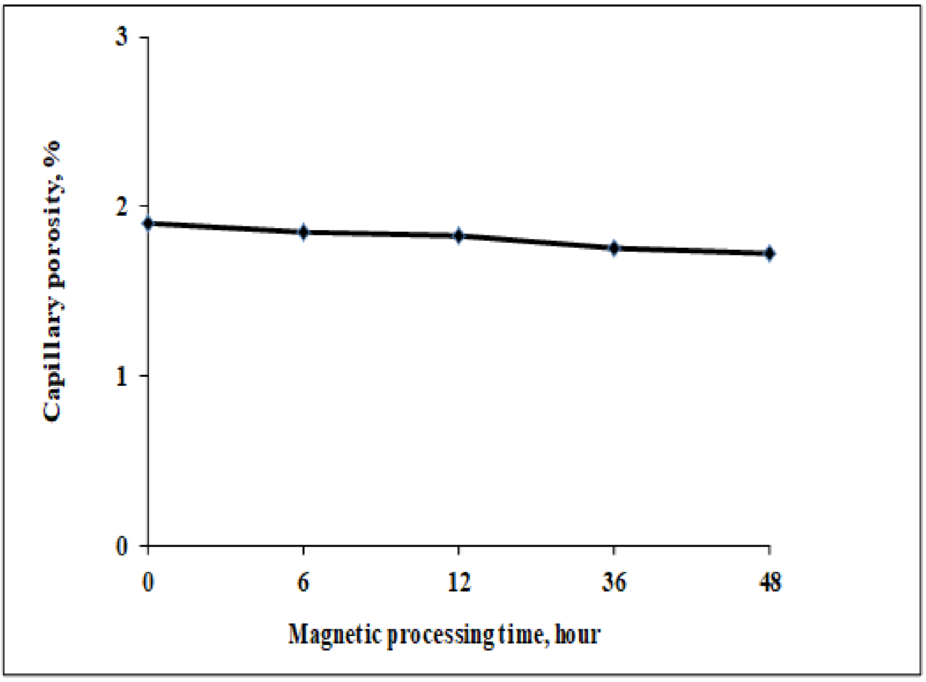

Fig. 5. Impact of magnetic treatment of curing water on capillary porosity.

3.3 Concrete Morphology

Figures 6a and 6b show the results obtained from SEM for control specimen (cured in tap water) and concrete specimen cured in magnetic water for 6 hours, respectively. It can be seen from SEM images that the microstructure of magnetically treated concrete is better than that of reference specimen cured in tap water, where, large amount of pores and crystals can be observed in the structure of control specimen (cured in tap water). The improvement in the microstructure of magnetically cured specimens can be attributed to the fact that using magnetic water increases the rate of both cement hydration and pozzolanic reaction. SEM observations are in good agreement with the mechanical results, where magnetically treated concrete showed a higher strength than that of concrete cured in tap water.

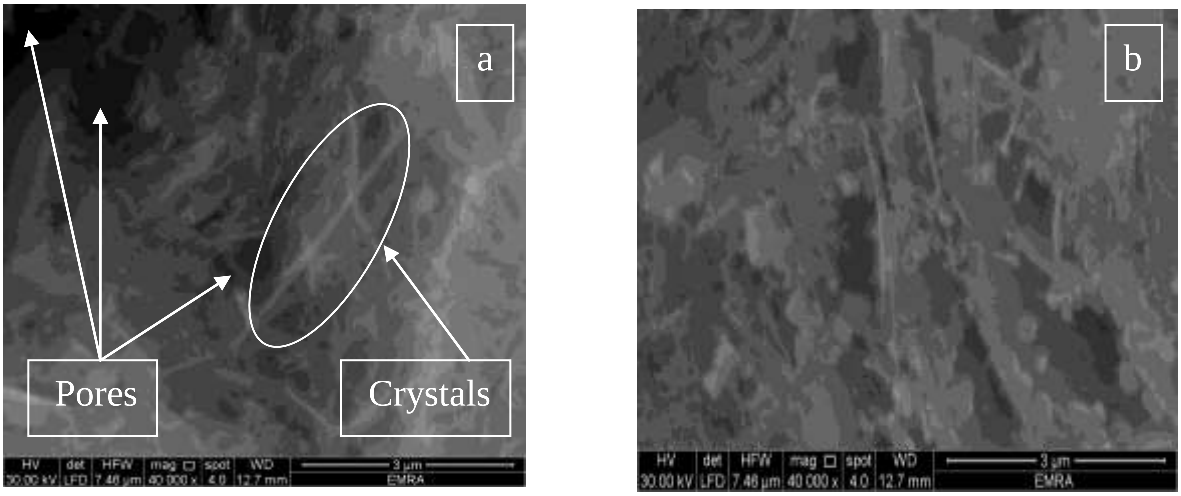

Fig. 6. SEM images for (a) reference specimen and (b) magnetically treated specimen.

4. CONCLUSIONS

Based on the experimental investigation, the main conclusions can be drawn as follow:

1. Magnetic treatment of curing water led to significant improvements on the compressive strength, tensile strength, and capillary porosity of concrete. This improvement was more obvious in the early ages (3 days and 7 days) of concrete than the late age (28 days).
2. Specimens cured in magnetic water for 48 hours showed the highest increase in 3-days and 28-days compressive strength (50% and 7%, respectively), reduction in 3-days and 28-days free lime content (55% and 8%) and reduction in 28-days capillary porosity (9%) compared to control specimens (TWSC).
3. Through the SEM images, it can be concluded that magnetic treatment of curing water enhances the microstructure of concrete by decreasing the amount of pores and large crystals that is responsible for the strength of concrete.

Generally, the results obtained from mechanical tests, de-sorption test, TGA, and SEM confirm the ability of magnetic water submerged curing (MWSC) regime to improve the mechanical and microstructure characteristics of concrete, especially in early ages. This increases the author's confidence in this approach as an alternative way to improve the early age mechanical behavior of concrete, as well as the possibility of using it in the fields of precast concrete, prestressed concrete, and repair works. Future studies are needed in the field of magnetic treatment of curing water in terms of magnet strength and magnetic processing time.

DECLARATION OF CONFLICT OF INTEREST

The author has declared no conflict of interests.

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المقاومة المبكرة والمتاخرة للخرسانة المعالجة مغناطيسيا

يهدف البحث الى ايجاد طريقة بديلة لزيادة معدل اكتساب الخرسانة للمقاومة فى اعمار مبكرة حيث تم استخدام نظام معالجة بغمر الخرسانة فى ماء عادى و نظام اخر مستحدث لمعالجة الخرسانة بغمرها فى ماء معالج مغناطيسيا وتم استخدام اربع فترات تعرض(٦، ١٢، ٣٦ و ٤٨ ساعة) لمجال مغاطيسى بقوة ١.٤ تسلا. تم تغير الماء المعالج مغناطيسيا كل ٦ ساعات وتم دراسة تأثير المعالجة المغناطيسية لماء المعالجة على سلوك الخرسانة بدلالة مقاومة الضغط و مقاومة الشد و المسامية الشعرية والتكوين الدقيق للخرسانة للاعمار المبكرة والمتاخرة وقد أوضحت النتائج المعملية أن المعالجة المغناطيسية لماء المعالجة ادت الى تحسين خصائص الخرسانة وبصفة خاصة فى الاعمار المبكرة واظهرت العينات المعالجة بالماء المغناطيسى لمدة ٤٨ ساعة اقصى مقاومة مبكرة (عمر ٣ ايام) ومقاومة متاخرة (عمر ٢٨ يوم) بنسب ٥٠% و ٧% على التوالى وانخفاض فى المسامية الشعرية بنسبة ٣٧% مقارنة بالعينات المعالجة بالماء العادى. اتفقت نتائج التكوين الدقيق مع الاختبارات الميكانيكية للخرسانة.