

## Effect of Rubber Treated by Acidic Solution on Some Mechanical Properties of Rubberize Cement Mortar

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Received on: 5/4/2011

Accepted on: 8/9/2011

### Abstract

In the present work, the properties of rubberize cement mortar containing crumb rubber treated by acidic solution are tested and compared with normal rubberize and normal cement mortar. The rubber, which is treated by different acidic solution such as: ( $H_2SO_4$ , HCl and  $CH_3COOH$ ) is used as a fine aggregate as volumetric partial replacement of sand in cement mortar. The percent of replacement ranged from 5 to 30%. Compressive strength, modulus of rupture and modulus of elasticity (static and dynamic) are retested for all mixes. Cubes of cement mortar also tested by ultrasonic pulse velocity (UPV) and hammer tests method to show the effect of treated rubber on the UPV and hammer tests and to demonstrate the possibility of this methods for estimating the compressive strength of rubberize cement mortar. The results show that the treatment of rubber by acidic solution significantly improves the properties of rubberize cement mortar. Moreover the results show that  $CH_3COOH$  gives better improvement compared with  $H_2SO_4$ . The treatment of rubber by HCl shows negative effects on all cement mortar properties.

**Keywords:** Rubberize Cement Mortar, Crumb Rubber, Acidic solution, Compressive Strength.

### تأثير المطاط المعالج بمحاليل حامضية على بعض الخصائص الميكانيكية لمونة الاسمنت المطاطية

#### الخلاصة

في هذا البحث تم دراسة خصائص مونة الاسمنت المطاطية الحاوية على مطاط معالج بالمحاليل الحامضية وتم مقارنة النتائج مع مونة الاسمنت المطاطية والاعتيادية. تم استخدام ثلاثة محاليل حامضية لمعالجة المطاط وهي ( $H_2SO_4$ , HCl and  $CH_3COOH$ ) حيث تم استخدام المطاط كنسبة حجمية تعويضة من حجم الركام الناعم وبنسبة تتراوح من 5 الى 30 بالمئة. تم قياس مقاومة الانضغاط ومقاومة الشد غير المباشر (معامل الكسر) ومعامل المرونة (الاستاتيكي والديناميكي) لجميع الخلطات. كذلك تم فحص المكعبات بطريقة الامواج فوق الصوتية وطريقة المطرقة وذلك لمعرفة سرعة الامواج فوق الصوتية وبيان امكانية وكفاءة فحص المطرقة في تخمين مقاومة الانضغاط للخرسانة المطاطية. بينت النتائج ان معالجة المطاط بالمحاليل الحامضية تحسن وبشكل ملحوظ خصائص مونة الاسمنت المطاطية. كذلك بينت النتائج ان استخدام  $CH_3COOH$  يعطي تحسنا ملحوظا واكثر من  $H_2SO_4$  بينما HCL يعطي نتائج عكسية.

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## Introduction

Waste rubber tires are a major component of solid waste. The United States Environmental Protection Agency (EPA) indicated that the manufacture of rubber tires for automobiles increased by 42% from 1960 to 1988. Currently, approximately 280 million waste tires are discarded annually in the United States alone. From this large number, only a few tires are recycled [1]. When the RMA began its scrap tire efforts in 1990, about 11% of scrap tires went to end-use markets, and one billion scrap tires were in stockpiles across the country. Today, fewer than 100 million tires remain in stockpiles, and more than 80% of scrap tires are utilized in end-use markets[2].

The disposal of waste tires is becoming a major waste management problem in the world. Landfill has been one of the most convenient ways of disposing of waste tires. As rubber tires are extremely durable and not naturally biodegradable, they will remain in landfill with very little degradation over time, presenting a continuing environmental hazard. One of the largest potential recycling routes is in construction, but usage of waste tires in civil engineering is currently very low.

Waste tires are difficult to ignite. Once ignited, however, tires will burn at a tremendously high temperature and are very difficult to extinguish.

Additionally, the doughnut shaped tire casings permit air drafts to stoke up the fire. A great tire fire can burn for several weeks or even months, at

times with marked effects on the neighboring environment. The air

contaminants from fires include polyaromatic hydrocarbons, CO, SO<sub>2</sub>, NO<sub>2</sub>, and HCl [3]. The high

temperatures of tire fires causes also the partial breakdown of the rubber into an oily material. Long-lasting burning boosts the likelihood of surface and groundwater pollution by this oily material.

Various studies have suggested that the rougher the rubber aggregate used in concrete mixtures the better the bonding developed between the particles and the surrounding matrix, and therefore the higher the compressive strength achieved. Tantalala et al. argued that if the bond between rubber aggregate and the surrounding cement paste is improved, then significantly higher compressive strength of rubberized concrete could be obtained and to achieve enhanced adhesion, it is necessary to pre-treat the rubber aggregate. However, there are many methods for pre-treatments vary from washing rubber aggregate with water to acidic etching, plasma pre-treatment and various coupling agents [4].

The workability and mechanical properties of mortar containing shredded automobile and truck tires were evaluated [5]. They showed that the addition of rubber particles resulted in a reduction of flexural

strengths of the mortar mixes. The decrease in strength was depended on the content of rubber granules or shreds and the shape of the shredded rubber. Preliminary results appeared to show that the addition of rubber shreds to mortar reduces the severity of the plastic shrinkage cracking compared with the control mortar.

Some papers presented some results of the mechanical behavior of the concrete filled with small volumetric fractions of crumbed tire rubber (also called rubberized concrete) [6, 7, 8 and 9]. Some dynamic results with different volume fractions of fiber and rubber, frequencies and temperatures were studied by Hernández-Olivares, F. et al. [10].

Segre et al. [11] showed that the small rubber particles (less than 300  $\mu$ ) could improve some of mortar properties even when used in high proportion if the rubber treated with NaOH. Also the additions of 10% NaOH-treated tire rubber particles in mortar reduce the water absorption significantly, and enhanced the resistance to acidic attack.

Al Bakri et al. [12] Studied the strength of concrete with rubber waste aggregate. This study attempts to use tire rubber as a partial replacement of aggregate to produce lightweight concrete. The principle target of the experimental was to determine the contribution of the waste rubber aggregate to the improvement of the strength behavior of the lightweight concrete.

Azmi et al. [13] studied the mechanical properties of rubberized concretes. Totally 15 concrete mixes

with three different water cement ratio (0.41, 0.57 and 0.68) were cast and tested for compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity. The results indicated that crumb rubber mixture was more workable as compared to normal concrete and can be acceptable to produce crumb rubber concretes. The results also indicated that the inclusion of crumb rubber in concrete reduce the static modulus of elasticity. Although there was a reduction in modulus of elasticity, the deformability of crumb rubber concrete increased as compared with normal concrete.

Khorrani et al. [14] studied the effect of using two groups of crumb rubber and two different types of treatment, the rubber particles were treated with carbon tetrachloride (CCl<sub>4</sub>) for 10 minutes and after that rubber particles were used in concrete mixture. The second treatment composed of two stages: firstly the rubber particles were treated with CCl<sub>4</sub> as mentioned above, and then they were treated with NaOH 40% for 10 minutes. Finally, the rubber particles were rinsed with tap water to remove the excessive NaOH solution. They showed that treating of rubber tire particles with carbon tetrachloride and NaOH has different effect on concrete properties. Carbon tetrachloride treated rubber particles improved the water permeability and water absorption of rubberized concrete, but it has a little positive effect on mechanical behavior of concrete.

Abdulla and others [15] Studied the effect of using crumb rubber treated with many alkaline materials on the properties of rubberize cement

mortar. They showed that the treating with alkaline materials significantly improves the properties of cement mortar. Moreover the results also showed that NaOCl gives better improvement more than NaOH and commercial detergent powder.

Aulse Wisam A. [16] studied the effect of using waste rubber as full replacement in all grading of fine aggregate to the mechanical properties of cement mortar. He showed that there is a reduction in strength for waste rubber mixture, also the modulus of elasticity reduce as the waste rubber content increase, and the result show the deformability waste rubber concrete decreasing compared to normal concrete.

**The aim of this study** is to investigate the effects of various amounts of crumb rubber of tires treated with acidic solution and used as partial replacement of sand in Ordinary Portland Cement mortar. Ultrasonic pulse velocity method used to compute the UPV (Ultrasonic Pulse Velocity) in the rubberize and normal cement mortar. Cubes of cement mortar also tested by hammer test method to demonstrate the possibility of this method for estimating the compressive strength of rubberize and normal cement mortar.

### Experimental Works

Cement mortar cubes of 5x5x5 cm are used for compressive strength test. Prisms of 4x4x16cm are used for modulus of rupture test. A volumetric ratio is 5, 10, 20 and 30% by volume of fine aggregate are chosen as partially replacing of fine aggregate with crumb rubber , Three types of acidic solution are used to treat the crumb rubber and study the effect of

this treatment on the mechanical properties of cement mortar.

### Materials

**Cement** :- Iraqi standard ordinary Portland cement produce by (UCC United Cement Company). The chemical and physical properties as shown in table(1).

**Rubber** :- The crumb rubber used is granulator and having a 2-2.36 mm nominal maximum size. The chemical and physical properties as shown in table(2).

**Fine Aggregate** :- Graded fine aggregate from Tuz city. The chemical and physical properties as shown in table(3).

**Acidic Solution** :-

a- HCl 35% , 5% .

b- H<sub>2</sub>SO<sub>4</sub> 35% , 5% .

c- CH<sub>3</sub>COOH5% (commercial type from Al-Badawy company) .

### Treatment of Rubber

Crumb rubber immersed in acidic solution for 24 hr and then rinsing it with water to be used in cement mortar as saturated surface dry , as shown in Fig. (1).

### Mixing

The mixing proportions 1:2.5(cement: sand by weight) with water cement ratio 0.4. The volumetric percent of crumb rubber are 5% , 10% , 20% and 30% as partial replacement of sand. The casting of cubes and prisms are made according to ASTM C 109/C 109M – 99 [16]and ASTM C348-97 [17].

**Results and discussion**

**Compressive strength**

Fig.2 shows the compressive strength of rubberized cement mortar (30% crumb rubber) for different acidic solution treatment. The rubberize cement mortar containing rubbers treated with H<sub>2</sub>SO<sub>4</sub> 35% gives a compressive strength of 2.07 times that of normal rubberize cement mortar and 0.73 of compressive strength for normal cement mortar, because the increasing in the roughness of rubber particles.

This figure shows also that using H<sub>2</sub>SO<sub>4</sub> and CH<sub>3</sub>COOH as treating materials will increase the compressive strength as compared with non-treated rubberize cement mortar. However, the treating by HCl 15% gives a slight increasing in compressive strength. On the other hand, HCl 35% gives negative effect on Compressive strength because it is a strong solution and treating crumb rubber with it would solve all dirt, oils and impurities from the rubber surface. The treated rubber could create better and stronger bonds with cement and in this way it should improve the concrete strength; but treating crumb rubber with HCl 35% may solve some rubber particles corners and reduces its irregularities which are very important and act as anchorages and improve concrete strength. The rubber inflated when reacted with the cement mortar also causing a crumbing during 48 hour.

**Modulus of Rupture**

The modulus of rupture of rubberize cement mortar is increased when using crumb rubber which is treated with CH<sub>3</sub>COOH and H<sub>2</sub>SO<sub>4</sub> as compared with normal rubberize cement mortar

and with rubberize cement mortar contain rubber treating with HCl as shown in Fig.(3).

Fig.(4) shows the prisms after test, the prisms contain rubber treated by CH<sub>3</sub>COOH having incline rupture line and the different to others prisms very clear, this is because the increasing in strength.

**Crumb Rubber Ratio Effect**

All acidic solution give the same reduction ratio in compressive strength when rubber ratio increase. However, increasing in crumb rubber ratio from 5% to 30% will decrease the compressive strength from 42.5 MPa to 24.26 MPa at 28-day age as shown in Fig.(5) for rubberize cement mortar which is treated with CH<sub>3</sub>COOH.

**Ultrasonic Pulse Velocity**

The relation between treating type and UPV (Ultrasonic Pulse Velocity) as shown in Fig.(2). This figure show that the UPV increases with increases of compressive strength. The modulus of elasticity also calculated by using ultrasonic pulse velocity test according to the device manual as shown in Fig.(6) from the following equations:-

$$E_s = 16667 (UPV^2 - 96.3UPV + 12.8) \dots(1)$$

$$E_d = 14286 (UPV^2 - 6.95UPV + 13.78) \dots(2)$$

Where: E<sub>s</sub>=Static modulus of elasticity and E<sub>d</sub>=Dynamic modulus of elasticity

Fig. (2) also show compressive strength by hammer test, this method gives results comparable to results obtained from Ultrasonic test when comparing the CH<sub>3</sub>COOH with

H<sub>2</sub>SO<sub>4</sub> treatment results. Thus, according to compressive test machine the best treating is H<sub>2</sub>SO<sub>4</sub> 35%, While according to hammer and ultrasonic test the best treatment is CH<sub>3</sub>COOH.

### Conclusions

- 1) Crumb rubber treated with CH<sub>3</sub>COOH improved cement mortar properties when compared with non treated rubberize cement mortar ( compressive strength, flexural strength, and modulus of elasticity ).
- 2) Using crumb rubber treating with H<sub>2</sub>SO<sub>4</sub> 35% increase compressive strength, modulus of rupture, and modulus of elasticity more than CH<sub>3</sub>COOH , while using HCl 35% gives negative effect.
- 3) Increasing in concentration of H<sub>2</sub>SO<sub>4</sub> from 5% to 35% lead to 14% increase in the compressive strength of rubberize cement mortar, as compared with CH<sub>3</sub>COOH treating.
- 4) The treatment of crumb rubber with concentrated hydraulic acid gives negative results where the rubber inflated when reacted with the cement mortar causing a crumbing during 48 hour.
- 5) The Ultrasonic pulse velocity test also prove that the treatment with H<sub>2</sub>SO<sub>4</sub> and CH<sub>3</sub>COOH gives positive results on the contrary of the hydraulic acid.
- 6) The Ultrasonic pulse velocity test showed that the velocity of pulse in the rubberize cement mortars containing the crumb rubber treated with CH<sub>3</sub>COOH faster than those treated with H<sub>2</sub>SO<sub>4</sub>, while the compressive test show the contrary.
- 7) Hammer test can using to estimate compressive strength of cement mortar with treated and non-treated rubbers.
- 8) Treating crumb rubber with CH<sub>3</sub>COOH and H<sub>2</sub>SO<sub>4</sub> give good improving in static and dynamic modulus of elasticity.
- 9) The relation between static and dynamic modulus of elasticity don't effect by treating type.

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**Table (1): Physical and chemical properties of cement**

Description	Content %	Limit of Iraqi specification No. 5/1984
Calcium oxide, CaO	64.5	-----
Silica, SiO <sub>2</sub>	13.4	-----
Alumina, Al <sub>2</sub> O <sub>3</sub>	4.6	-----
Iron oxide, Fe <sub>2</sub> O <sub>3</sub>	3.5	-----
Magnesia, MgO	2.5	5 % Max.
Sulfate, SO <sub>3</sub>	1.1	2.8 % Max.
Loss on Ignition, (L.O.I)	0.95	4 % Max.
Insoluble material	1.05	1.5 % Max.
Lime Saturation Factor, (L.S.F)	0.9	(0.66-1.02)
Specific surface area (m <sup>2</sup> /kg)	301.5	>250 m <sup>2</sup> /kg
Initial setting, hrs : min	0:55	> 45 min
Final setting, hrs : min	7:00	< 10 hrs
3-day f'c MPa	28.7	>15 MPa

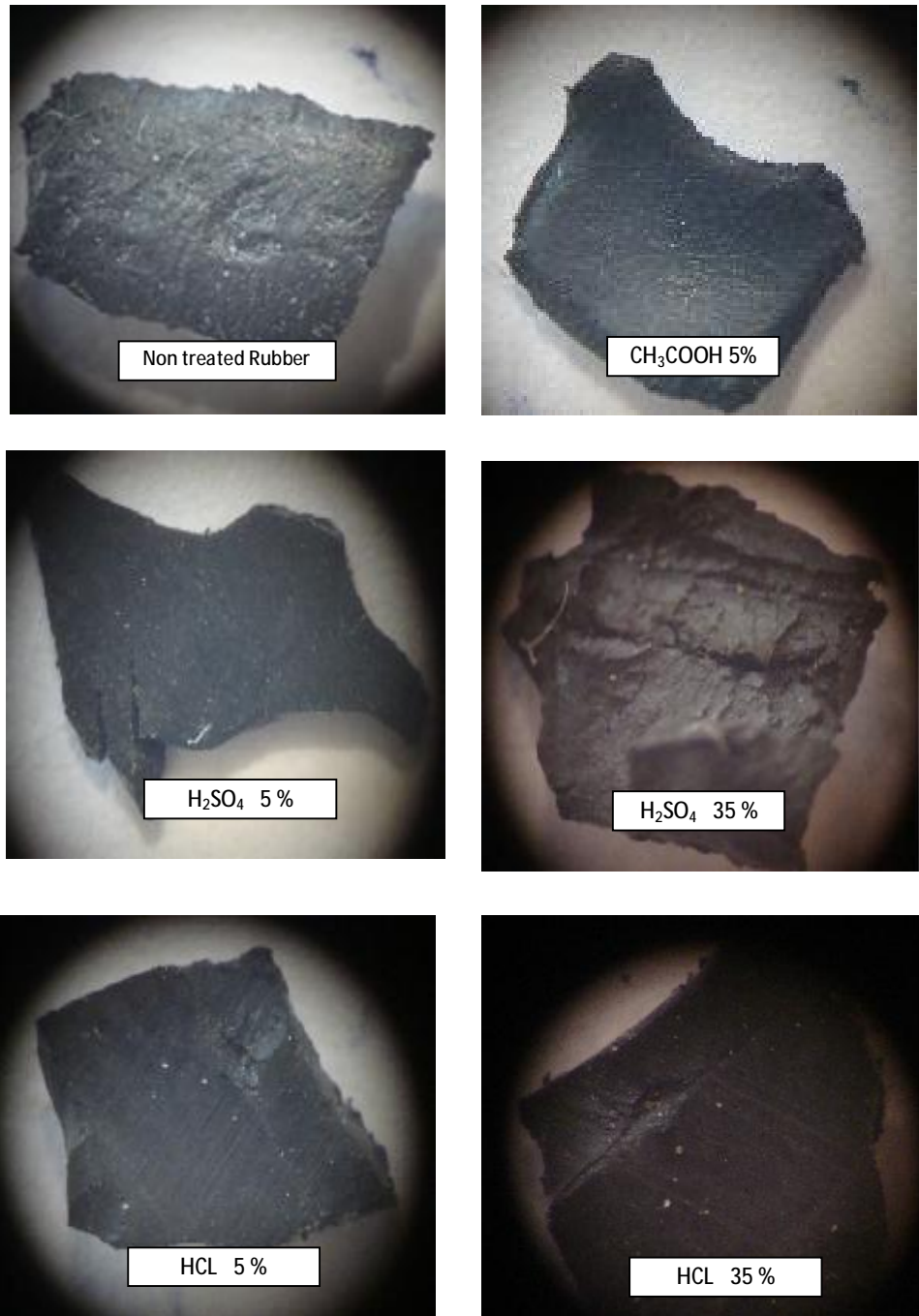
**Table ( 2 ) Chemical and physical properties of crumb rubber**

No.	Description	Content %
1	Average bulk specific gravity	1.10
2	Moisture content	1.1
3	Ash content	7
4	Average absorption	1.4
5	Fineness modulus	3.4
6	Rubber hydrocarbon	50
7	Specific gravity	1.07
8	Polymer	54



**Table (3): Grading, chemical, and physical properties of fine aggregate**

Grading of fine aggregate			
Sieve size	Cumulative passing %	Limit of ASTM C33-01	
9.5-mm	100	10- 0	
4.75-mm	91.34	95 - 100	
2.36-mm	83.8	80 - 100	
1.18-mm	67.73	50 - 85	
600- $\mu$ m	20.3	25 - 60	
300- $\mu$ m)	2.45	5 - 30	
150- $\mu$ m	0	0 - 10	
Chemical and physical properties			
<i>Properties</i>	<i>Specification</i>	<i>Test Results</i>	<i>Limits of specification</i>
Specific gravity	ASTM C128-01	2.60	
Absorption %	ASTM C128-01	2.2	
Dry loose unit weight, kg/m <sup>3</sup>	ASTM C29/C29M/97	1590	
Sulfate content (as SO <sub>3</sub> ), %	(I.O.S.) No. 45-84	0.08	<0.5
Material finer than 0.075 mm% sieve	(I.O.S.) No. 45-84	1.3	<5.0



**Figure (1): Electronic microscopy photo (45X) for treated and non-treated rubbers**

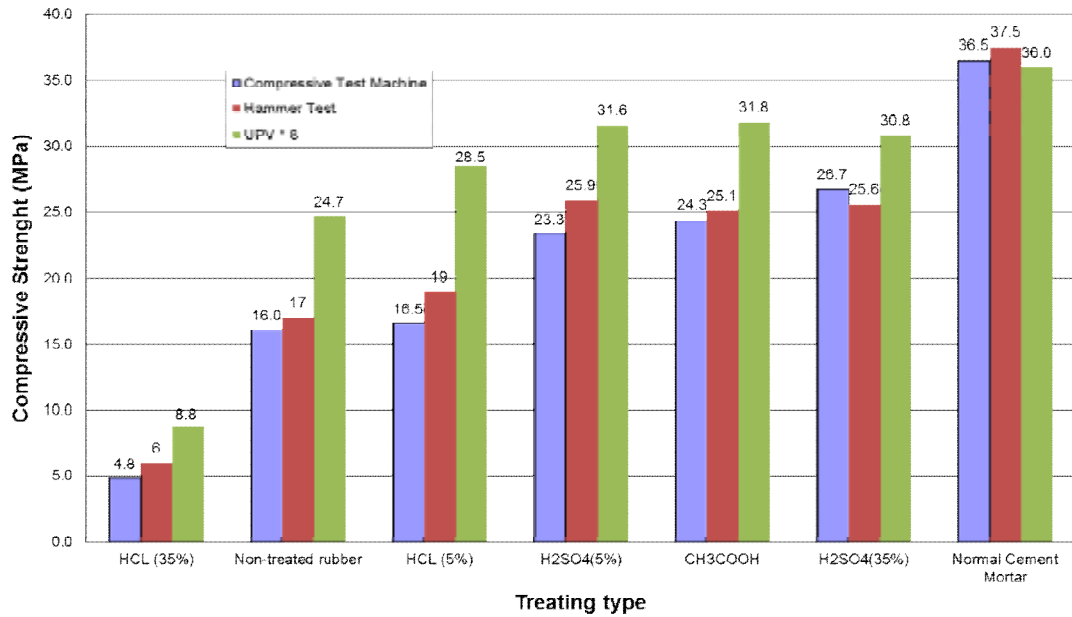


Figure (2) Effect of treating type to the 28-days compressive strength of rubberize cement mortar

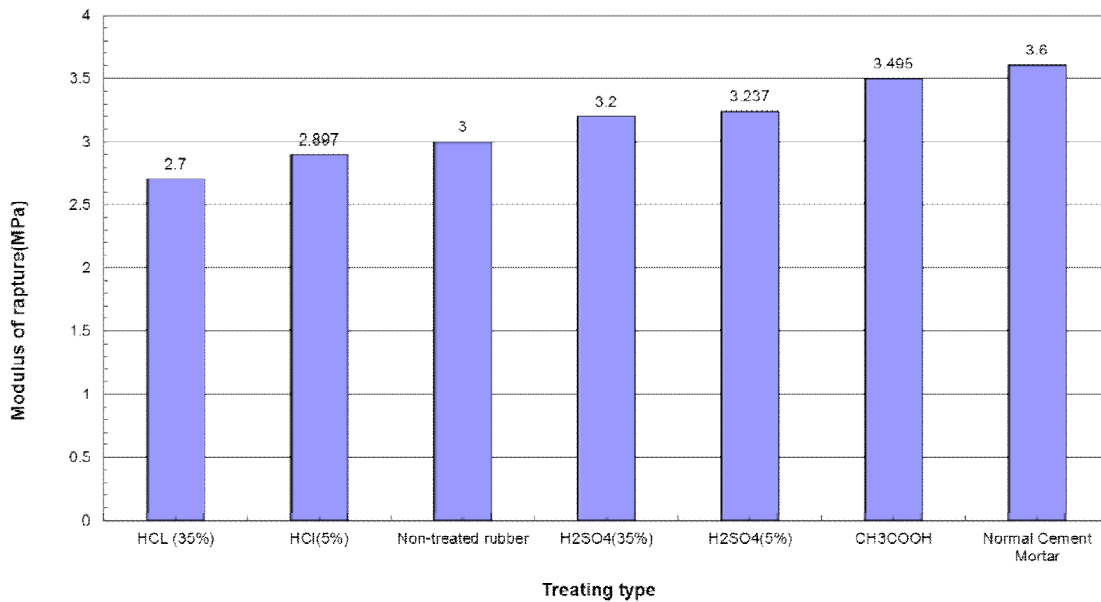


Figure (3) Effect of treating type to modulus of rupture

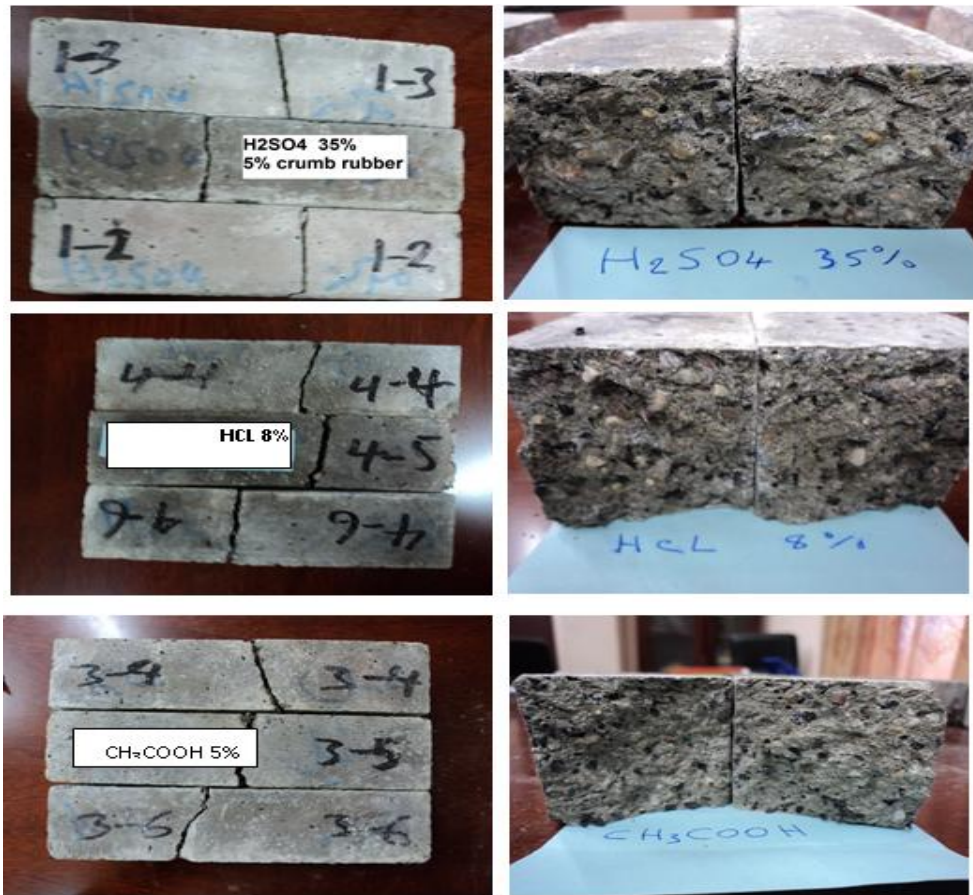


Figure (4) Rubberize cement mortar prisms after flexural test

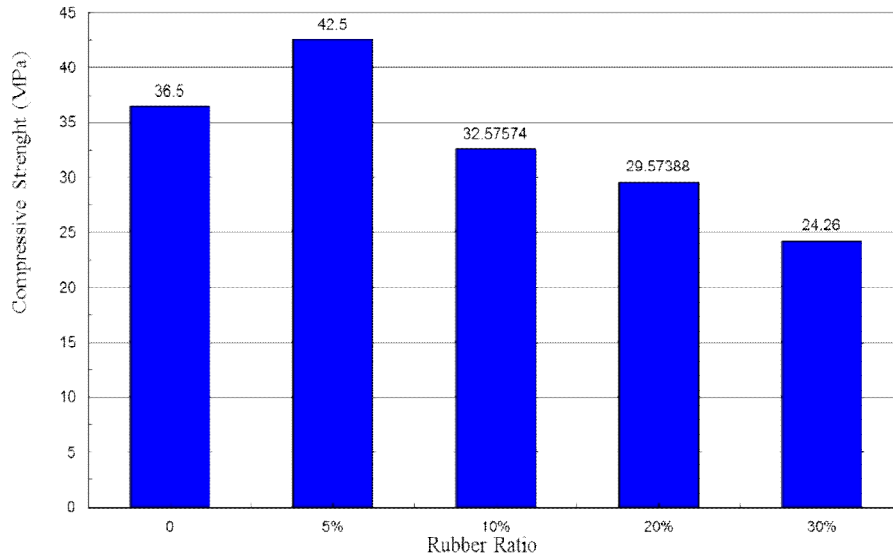


Figure (5) Effect of rubber ratio to the compressive strength of rubberize cement mortar treating with  $CH_3COOH$

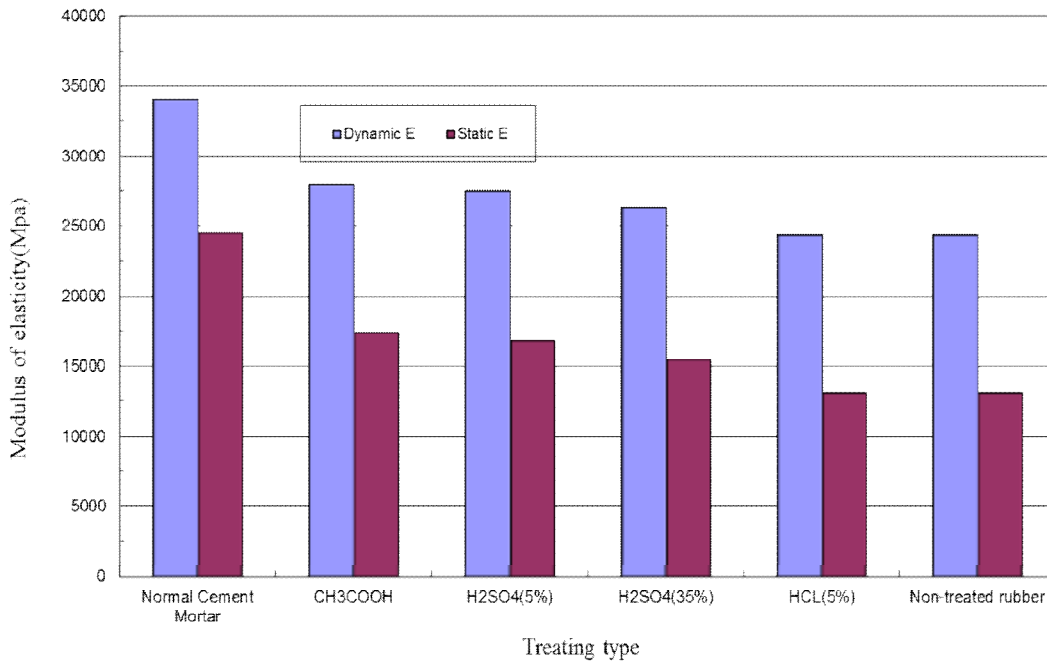


Figure (6) Effect of treating type to the modulus of elasticity



Figure (7) Hammer test of rubberize cement mortar  
cubes