CHEMICAL ENGINEERING TRANSACTIONS

VOL. 55, 2016

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-46-4; **ISSN** 2283-9216

DOI: 10.3303/CET1655067

Research on Mechanical Properties of Steel Fiber Reinforced Rubber Concrete

Yonggang Mi*, Yunhe Liu

School of Civil Engineering and Architecture, Xi'an University of Technology, Xi'an 710048, China.
miyonggang2006@163.com

The purpose of this paper is to research on the mechanical properties of steel fiber reinforced rubber concrete in this paper. Cracks, deformation and other issues often exist in the process of using concrete, a commonly used building material. Adding a certain amount of powder or rubber particles in concrete can be a good solution to these problems. This work studied construction technology of green rubber concrete. It is found that only by emphasizing the selection of tire and rubber particles as well as fabrication and application of rubber concrete can the quality of construction engineering be improved to the highest extent, based on the concept and characteristics of rubber concrete and combining them with the status of their applications in building construction.

1. Introduction

Crumb Rubber Concrete (CRC) is one type of “young” building materials, with less than thirty years of history. CRC exhibits many different mechanical behaviors from those of conventional concrete. Current studies reveal that (1) CRC improves its anti-cracking behavior; (2) CRC increases in the resistance to water and chloride penetration; and (3) CRC exhibits large deformability and energy-absorbing capability. These macro properties of CRC have a close relationship with its microstructure and would affect the structural properties. In this regards, it is important to “read” CRC in the view of microscopic scale and explore its influence on structural properties.

With the development of building technology, demands for high-performance materials are growing. In traditional architecture, mud and stones and other materials are mainly used, resulting in poor quality of construction and impossibility of constructing high rise buildings. Yet with the development of modern natural science and technology, the discipline of material science emerges, playing a significant role in the construction sector (Siddique et al., 2004). For example, the use of steel, concrete and other materials can greatly improve the quality of construction work. Subject to historical factors, China started late in science and technology and there are still gaps between China and some western countries in the study of concrete and other materials. Especially with the emergence of skyscrapers in recent years, the requirements for the performance of concrete are higher. In this context, different materials are added to the concrete according to practical needs, creating some new features in concrete. For example, adding powder or rubber particles can produce high flexibility in the concrete (Hernández-Olivares et al., 2002). Although concrete is one of the most commonly used building materials, it does not always meet the requirements due to the high brittleness. It has been observed from some previous research that the properties of concrete will be improved when the used automobile-tire chips are added into concrete. As a new material rubber concrete can not only improve the performance of concrete but also solves the problem of dealing with waste tires. This is a kind of resource saving and environment-friendly material, which has a broad application prospect in civil engineering. As a kind of hyper-elastic material, rubber primarily improves the internal structure of concrete through physical interaction without changing the chemical properties of each component in the concrete. Adding the rubber particles greatly improve the properties of shock absorption, impact resistance, spilling resistance, heat and sound insulation and etc. The figure 1 shows the steel fiber reinforced rubber concrete roof.

Please cite this article as: Mi Y.G., Liu Y.H., 2016, Research on mechanical properties of steel fiber reinforced rubber concrete, Chemical Engineering Transactions, 55, 397-402 DOI:10.3303/CET1655067

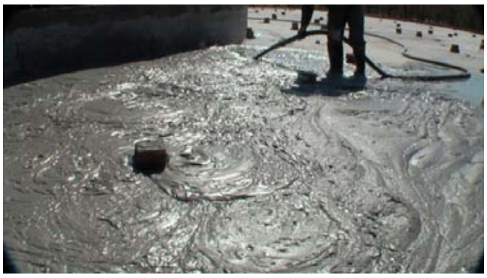

Figure 1: The steel fiber reinforced rubber concrete roof

2. Analysis of rubber concrete

Concrete plays an important role in construction. The use of concrete has greatly improved the quality of construction, so it is highly valued. But with the development of the construction sector itself and the emergence of complex engineering works, concrete of superior performance must be used in order to complete these projects and demands for properties of concrete are even various (Toutanji et al., 1996). In this context, certain materials are added to concrete to promote better performance of the concrete. Naturally, tire and rubber particles are added to concrete to make rubber concrete, because rubber has good elasticity while concrete often causes cracks, deformation and other issues and even accidents in the process of using and after completion. Adding powder or rubber particles into concrete can ensure certain flexibility of the concrete, thereby avoiding cracks. In traditional concrete construction, water is easy to penetrate the interior, corrosion steel and other materials, while rubber concrete can increase tightness. Thus, the use of rubber concrete can improve the performance of concrete from different aspects.

Rubber concrete has distinctive features compared with ordinary concrete. Above all, rubber concrete has good flexibility, effectively preventing the building deformation, increasing the building. Airtight is keeping water from penetrating into the concrete and protecting the steel and so on. Out of practical applications, people can add other materials to concrete to achieve the same goals but at a higher price than rubber. Consequently, the use of rubber is common now, producing a lot of waste and large amounts of polluting gases when it is being burned due to its corrosion resistance. Especially with the shorter lifespan of rubber products, such as three years for car tires, and the popularity of automotive applications, a large number of rubber garbage is produced annually. Therefore disposal of these rubber wastes has become an important issue. This shows that adding powder and rubber particles to concrete can not only control the costs well, but can also solve environmental problems to a certain extent. Due to rubber concrete's lower requirements to rubber; it is essential to make waste rubber products into the form of powder or granules after simple treatment. It is precisely these characteristics of rubber concrete that make it widely used in modern building construction (Hernández-Olivares et al., 2004).

With the limitation of technology in China, the study of new materials such as rubber concrete started late. While in the late eighties, the United States had already began to conduct researches on rubber concrete, adding a powder and granular form of rubber to concrete to improve the performance of concrete. Still, actual survey found that adding different components of powder and granules differentiated the performance of the concrete. However, due to the low level of technology at the time, the performance of rubber concrete could not be controlled well. With the development of material science and construction engineering, rubber concrete has been highly valued and widely used in the actual construction due to its superior performance (Khaloo et al., 2008). Through practical researches, people have gotten a deeper understanding of the impact of different amounts of tire and rubber particles to the concrete's properties. In the actual construction, people were targeted to select powder or rubber particles as well as the specific components according to the actual needs. Due to the low level of technology, rubber concrete in China (Batayneh et al., 2008) has a relatively short-time development. The real estate market in China has been hot in recent years, so out of the actual need for building construction and China's actual situation, some foreign advanced technology has been learned and the country's rubber concrete technology has been improved. Also, to maximize the performance of rubber concrete, some simple experiments will be carried out in the field in the actual construction process (Cheng et al., 2014).

3. The rubber concrete model and algorithm

Rubber concrete has been widely applied after years of development and improvement. People continue to improve rubber concrete in the process of use, making rubber concrete relatively perfect (Shu et al., 2014).

According to the actual needs, people are targeted to match proportions of rubber concrete. As basic materials in construction, the rubber concrete's performance can directly affect the quality of the project, so factors that affect the use of it must be paid attention to. The figure 2 shows the basic figure for mechanical properties (Thomas et al., 2014).

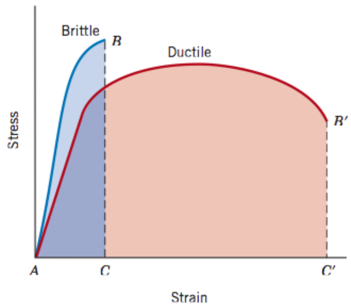

Figure 2: The basic figure for mechanical properties

There are lots of such factors in the actual building construction. The first one is the operator's professional quality. The operator works to mix and stir rubber concrete, only sufficient technical skills ensuring the properties of rubber concrete. The second factor is rubber concrete material itself. In making rubber concrete, people get sand and mud around the construction site to facilitate the construction project. Due to different geological conditions in different regions, sand stone and mud vary in performance. As a result, the performance of rubber concrete will be greatly impacted by materials in poor geological conditions. Besides, environmental factors should be considered because rubber emits toxic gases. Correspondingly, rubber concrete should be handled properly in order not to influence the construction project and the personnel's health.

Green rubber concrete has been very widely used in building construction because of its characteristics. And it is applied in China's construction sector but the limited technical level causes many problems in the actual applications. To start with, it is the lower quality of the construction workers. They cannot get a good grasp of the ratio of rubber concrete as well as the amount of powder and rubber particles to be added according to the actual needs. Next it comes the law level of environmental protection. Most of the rubber used in rubber concrete is junk, the majority being automobile tires. These rubber products have little to do with environmental protection and emit harmful gases in the production process. Therefore, these rubber materials will be exposed in indoor environment and greatly impact human health if not properly disposed. Actual survey finds that currently less rubber concrete has been used in building construction in China despite of people's realization of its importance. The main cause of this phenomenon is fewer manufacturers of powder and rubber granules meanwhile with a relatively backward production process. They are unable to meet the needs of the actual use of rubber concrete. Thus, it is necessary to intensify research on rubber concrete to improve its application in China.

Assume that the input of question is a pattern set $\{xi\} \subset Rd$ composed of second-type object. If any object xi belongs to the first type, mark it as 1, if it belongs to the second type, mark it as -1. Take n samples from collection as training set, as is shown in (1) (hunag et al., 2016):

$$(x_i, y_i) i = 1, 2, 3, \ldots, \mathrm{n} \quad y_i = \begin{cases} = 1 \\ = -1 \end{cases} \tag{1}$$

The final purpose of Support Vector Machine is: based on selected training set, a discriminant function is formed to distinguish the second type model correctly.

In mathematics, hyperplane is linear subspace whose codimension equals 1 in eulidean n-spaces. This is the extension of straight line in plane and plane in space. Assume that F is domain, hyperplane in Fn of eulidean n-spaces is shown in (2)

$$a_1 x_1 + a_2 x_2 + \ldots + a_n x_n + b = 0 \tag{2}$$

The defined subset, among which is the constant all of which are not zero, as is shown in (3)

$$\langle w, x_i \rangle + b = 0 \tag{3}$$

So, if hyperplane exist to make

$$\langle w, x_i \rangle + b \geq 1 \;\; y_i = 1 \tag{4}$$

$$\langle w, x_i \rangle + b \leq -1 \; y_i = -1 \tag{5}$$

Therefore, domain F is linearly separable. Generally, F is called training set, and there exists such hyperplane of the training set which is also linearly separable.

$$h_j = \exp\left(-\frac{\|X - C_j\|}{2b_j^2}\right), \quad j = 1, 2, ..., m \tag{6}$$

The output of the network is given as:

$$y_m(k) = wh = w_1h_1 + w_2h_2 + ... + w_mh_m \tag{7}$$

Assuming the ideal output is y (k), the performance index function is:

$$E(k) = \frac{1}{2}\left(y(k) - y_m(k)\right)^2 \tag{8}$$

The equation of basic function is as equation (9) as follows:

$$\partial_j (C_{ijkl}\partial_k u_l + e_{kij}\partial_k \varphi) - \rho \ddot{u}_i = 0 \tag{9}$$

Under the linear relationship, basic equation is shown in equation (2):

$$\partial_j (e_{ijkl}\partial_k u_l - \eta_{kij}\partial_k \varphi) = 0 \tag{10}$$

The linear differential equation can be expressed into the following simplified forms:

$$L(\nabla, \omega) f(x, \omega) = 0, \; L(\nabla, \omega) = T(\nabla) + \omega^2 \rho \mathrm{J} \tag{11}$$

In which,

$$T(\nabla) = \begin{Vmatrix} T_{ik}(\nabla) & t_i(\nabla) \\ t_k^T(\nabla) & -\tau(\nabla) \end{Vmatrix}, \; \mathrm{J} = \begin{Vmatrix} \delta_{ik} & 0 \\ 0 & 0 \end{Vmatrix}, \; f(x, \omega) = \begin{Vmatrix} u_k(x, \omega) \\ \varphi(x, \omega) \end{Vmatrix} \tag{12}$$

4. The experiment and result analysis

For rubber concrete, the selection of tire and rubber particles is important. It not only directly affects the performance of rubber concrete, but also impacts costs. There are currently lots of manufacturers producing powder and rubber particles on the market, offering a variety of powder products to meet the needs of different areas. In the actual selection, optimal and targeted powder or rubber granules should be selected according to the actual needs as well as the using effect of powder. Actual survey finds that marry of currently available powder and rubber particles are produced by foreign companies. While some production companies in China represent a large gap with foreign companies in the powder properties. For cost considerations, some construction units will choose products from China's companies in actual building construction due to the relatively low price of tire and rubber granules. It often results in quality problems after completion. This shows the importance of the selection of tire and rubber particles.

By the actual construction process, certain experiments will be conducted after the selection to ensure the performance of the powder and rubber particles. And if conditions permit it, they can be taken to the laboratory to detect with professional testing equipment to make a comprehensive understanding of it.

The proportion and mixing are very important for ordinary concrete, the same being true of rubber concrete. Adding material to concrete increases the difficulty of the proportion and mixing. Therefore the operator must understand the specific properties of concrete in different proportions in order to take good control of its performance. It is the only way to grasp the added amount of powder or rubber particles to make rubber concrete meet the needs of the actual construction. In the actual making process, the operator should pay attention to the ratio of ordinary concrete apart from powder and rubber particles. Because adding powder will affect the performance of normal concrete, mechanical experiments should be initiated in the field to ensure the performance of rubber concrete and meet the needs of actual application. The rubber concrete can only be used after the test of practice. In China's production of rubber concrete, the staff merely adds some powder or rubber particles to ordinary concrete based on their work experience due to their low qualities. Although in this approach, properties of rubber concrete can be improved, the targeted ratio cannot be accomplished according to the actual situation of the construction project. For example, some of the concrete possesses a certain degree of flexibility but still cannot meet the needs of practical use since some parts require higher elasticity. Figure 3 shows the tensile property and flexure property.

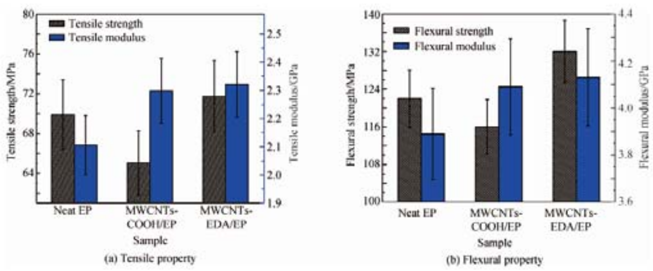

Figure 3: The tensile property and flexure property

According to the previous analysis, different adding amounts of powder and rubber particles will differentiate the performance of rubber concrete. Taking the complexity of the current project into account, different parts of the construction require various materials in the actual building construction. So the added amount of powder and rubber particles should be controlled to meet the needs of different parts of the project. Thus the use of rubber concrete should be targeted. The operator should analyze the project program and get specific understanding of different parts' needing components of concrete, to produce the corresponding amounts of rubber concrete. In practical construction, different parts of the construction using rubber concrete with corresponding properties can improve the quality of construction works in large parts. This plays an important role in the construction of the project. Given the complexity of building construction, the rubber concrete usually requires site fabrication. After fabrication, simple experiments should be conducted in the field to verify some important properties of rubber concrete in order to the performance of concrete. Only the authenticated materials can be used in the actual construction, so that the quality of construction projects can be well controlled. Figure 4 shows the XRD result.

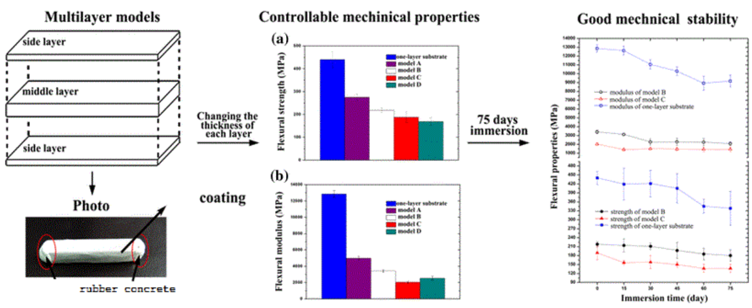

Figure 4: The experiment result

XRD results show that although the chemical constituents of cement is complicated, no new phase is found in the hydration products of the cement paste incorporating crumb rubber; The peak intensity of calcium hydroxide (CH) from the hydration products of the cement paste incorporating crumb rubber is reduced significantly compared to that from the control blends. This suggested that cement-based materials incorporating crumb rubber would have a larger growth in strength in late time, and this suggestion is preliminarily supported with a set of experimental data by other searchers. Through the pore structure and fractal characteristic of CRC which is analyzed quantitatively using MIP, the results show that the Mode Pore

Diameter, the Mean Pore Diameter, the Median Pore Diameter and the porosity of CRC are increased compared to those of conventional concrete, and the pore distribution scope of CRC becomes wide. The fractal dimension D of the pores in CRC decreases with the increase of the crumb rubber content, which indicates that the pore distribution tends to becomes regular when rubber is added. A finite element model for a rectangular plane containing an elliptic hole in the center is established based on stress concentration theory. This model illustrates the mechanism of rubber's delaying the multiplication of the crack in CRC and explains why CRC exhibits high ductility. Stress concentration factor (SCF) is introduced to measure the stress concentration degree. It is found from the results that SCF increases significantly as the shape factor of the elliptic hole increases. Soft filler decreases the SCF and reduces the affected area of the hole along x and y directions. This research is helpful in explaining why CRC can exhibit ductile failure mode even in low temperature. A modified stress-strain relationship for CRC which is proposed in section 3 shows based on this, theoretical formula for the flexural capacity of CRC beam, which take into account the peak compressive strain and the ultimate compressive strain of CRC, is established. The neutral axis moves downward remarkably because of the large ultimate compressive strain of CRC, which results in the compressive zone of CRC beam increases significantly. The calculation results show that with the same grade of concrete strength the flexural capacity of CRC beam is increased by 0.10% (when rubber content is 0.12%, namely, $\lambda 1 \leqslant 1.5$; $\lambda 2 \leqslant 2.0$). An example shows that the flexural capacity of the CRC beam is increased by 7.6%. Based on the modified stress-strain relationship of CRC, ductility evaluation method is used by means of curvature ductility factor (CDF). The method indicates that the peak compressive strain and the ultimate compressive strain of concrete affect the ductility of concrete beam significantly as well as reinforcement ratio and yield strength of steel. In the end, a comparison shows that the calculated ductility of a reinforced CRC beam is about as 1.642.59 times as that of a conventional concrete beam.

4. Conclusions

By analysis of the full text, it can be seen that rubber concrete has been highly valued because of its distinctive features of improving features of ordinary concrete including its elasticity and tightness and preventing problems such as cracks in the concrete. In addition, powder and rubber particles are mostly produced from discarded automobile tires, promoting the disposal of waste rubber. As a consequence, the use of rubber concrete is very common in current building construction. In conclusion, the selection of powder and rubber particles as well as actual matching proportions must be highly valued in order to well control the performance of rubber concrete. Plus, after fabrication of rubber concrete, simple experiments can be conducted in the field to ensure that its performance meets the needs of actual construction.

Reference

Batayneh M.K., Marie I., Asi I., 2008, Promoting the use of crumb rubber concrete in developing countries. Waste Management. 28, 11, 2171-6.

Cheng Z., Shi Z., 2014, Vibration attenuation properties of periodic rubber concrete panels. Construction & Building Materials. 50, 257-265.

Hernández-Olivares F., Barluenga G., 2004, Fire performance of recycled rubber-filled high-strength concrete. Cement & Concrete Research. 34, 1, 109-117.

Hernández-Olivares F., Barluenga G., Bollati M., Witoszek B., 2002 Static and dynamic behaviour of recycled tyre rubber-filled concrete. Cement & Concrete Research. 32, 10, 1587-1596.

Hunag L.J., Wang H.Y., Wu Y.W., 2016, Properties of the mechanical in controlled low-strength rubber lightweight aggregate concrete (CLSRLC). Construction & Building Materials. 112, 1054-1058.

Khaloo A.R., Dehestani M., Rahmatabadi P., 2008, Mechanical properties of concrete containing a high volume of tire–rubber particles. Waste Management, 28, 12, 2472-2482.

Shu X., Huang B., 2014, Recycling of waste tire rubber in asphalt and portland cement concrete: An overview. Construction & Building Materials. 67, 2, 217-224.

Siddique R., Naik T.R., 2004, Properties of concrete containing scrap-tire rubber--an overview, Waste Management. 24, 6, 563-9.

Thomas B.S., Gupta R.C., Kalla P., Cseteneyi L., 2014, Strength, abrasion and permeation characteristics of cement concrete containing discarded rubber fine aggregates. Construction & Building Materials. 59, 21, 204-212.

Toutanji H.A., 1996, The use of rubber tire particles in concrete to replace mineral aggregates. Cement & Concrete Composite. 18, 2, 135-139.