STUDY ON USING GRINDING PRODUCTS FROM WASTE RUBBER TO REPLACE A PART OF THE AGGREGATE IN CEMENT CONCRETE PRODUCTION

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Abstract

The article presents research results using crushed products from waste rubber to replace a small aggregate and large aggregate part in the manufacture of cement concrete. First, rubber mixtures are classified according to the particle size group corresponding to the size of aggregate to be replaced. Then, small aggregate and large aggregate, at the same time, are replaced by rubber particles with different proportions. The research results show that it is completely possible to fabricate cement concrete grade M20 - M30 when replacing 10-25% of the aggregate volume with a rubber mixture having the same particle size. This has great significance in the search for alternative raw materials to make concrete, in order to reduce the exploitation of natural resources, contribute to limiting environmental pollution, and towards the goal of sustainable development.

Keywords: *Recycled rubber particles; waste rubber; replace the aggregate; concrete; sustainable development.*

1. Introduction

In recent years, the economy has developed strongly; the travel demand of people and the number of motorized means of transport, such as car, motorbike have increased rapidly. Over time, along with the rapid growth of road traffic and motor vehicles, a large number of damaged old tires that are no longer usable have been discarded, leading to environmental pollution. It is estimated that over the past 10 years, there have been about 2-3 billion waste tires that have been stored in contravention of regulations across the US and an equivalent number in European countries [3, 4]. Data from the Vietnam Registry Department (2011) also shows that the annual demand for tires is about 35-40 million tires, of which the demand for replacement tires accounts for 80%. In addition, many other items made from rubber at the end of their useful life are also discharged into the environment and have not had a plan for thorough treatment (bumpers, conveyors, rugs, carpets, rubber gaskets). The collection, storage, treatment or disposal, landfill of these types of waste are at risk of creating negative impacts on the environment and human health, especially the amount of waste from tires. The annual waste is disposed of in huge quantities, posing a great challenge for many countries.

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Current treatment methods, such as burning in incinerators, open burning, or landfill do not solve the problems of air, soil, and water pollution. Therefore, finding effective solutions to collect, process, and reuse waste rubber appropriately is a necessary issue, not only contributing to saving resources but also contributing to minimizing the problem of relevant environmental contamination. This is a problem that has received great attention in many countries around the world. However, the current rate of collection and reuse of waste tires in many countries as well as in Vietnam is still very modest.

The previous authors considered an individual replacement rate from 2.5% to 100% by volume of large aggregate or small aggregate, or by replacing both aggregates at the same time, the workability of concrete mixes would be reduced when the content of rubber particles/flakes increases, except for the case of using superplasticizer, the impact level will be reduced significantly. Usually when the replacement rate is small (less than 20%) combined with the use of superplasticizer will not change the slump much [5-8], while with a larger replacement rate or no additives, it will reduce the slump of the concrete mixture [9-11]. The compressive strength of the concrete also decreases when the content of replacement rubber increases to 15% [12-14]; the modulus of elasticity of the concrete is noted to decrease with increasing the rubber content in the concrete instead of the aggregate [15, 16]. In Vietnam, up to now, there are very few studies using recycled products from waste rubber to make cement concrete. The studies, if any, are only assessing the possibility of using scrap rubber pieces/particles to individually replace a small aggregate or a large aggregate part to make cement concrete.

Rubber is a fairly sustainable material; it takes hundreds of years to decompose rubber, while the average life expectancy of concrete structures is usually thirty to fifty years. Furthermore, rubber is a stable material in an alkaline environment, so rubber has the ability to survive and be sustainable in concrete environments.

From the surveyed experiments, it can be used the grinding products from rubber tires to replace a part of aggregate to produce conventional concrete. In addition, the use of rubber particles/particles is also effective to improve some properties of concrete, such as reducing the volume of concrete, increasing elasticity, reducing vibrations.

Therefore, it is completely feasible to continue researching and using crushed products from waste rubber to make cement concrete. The produced cement concrete is capable of being applied to appropriate construction projects, providing benefits about economics and the environment for the society.

2. Materials and research methods

2.1. Cement

The type of cement used in this study is Hoang Thach PCB40 mixed Portland cement, with mechanical properties meeting the requirements of TCVN 6260: 2009. Test results to determine the mechanical properties of cement were conducted according to TCVN 6016:2011, TCVN 6017:2015, TCVN 4030:2003 and shown in Table 1.

Table 1. Mechanical properties of Hoang Thach cement PCB40

Items	Value
Density, g/cm^3	3.05
Fineness (the amount leftover on a 90 μm sieve), %	5.4
Standard ductility, %	29.5
Coagulate start time, minutes	120
Coagulate end time, minutes	215
The intensity of age 28 days, MPa	43.7

2.2. Crushed stone

Crushed stone used in the study was exploited at Phu Ly - Ha Nam (D_{max} = 20 mm and had physical and mechanical criteria to meet the requirements of TCVN 7570-2006). The experimental results of major physical and mechanical properties of crushed stone according to TCVN 7572-2006 are shown in Table 2.

Table 2. Some physical and mechanical properties of crushed stone

Items	Value			
Sieve size, (mm)	5	10	20	40
Residual mass accumulated on the sieve, (%)	94.6	60.2	7.9	0
Density, (g/cm^3)	2.67			
Absorption of water, (%)	0.67			
Porosity volume mass, kg/m^3	1438			
Crushed compression strength in cylinders, (%)	11.3			
Content of rhombus and flatform particles, (%)	3.8			
Content of dust, mud, clay, (%)	0.34			

2.3. Sands

The sand used in the study is Song Lo sand; they have physical and mechanical criteria to meet the requirements of TCVN 7570-2006. The test results of major physical and mechanical properties of sand according to TCVN 7572-2006 are shown in Table 3.

Table 3. Some physical and mechanical properties of Song Lo sand

Items	Value					
Sieve size, (mm)	5	2.5	1.25	0.63	0.315	0.14
Residual mass accumulated on the sieve, (%)	0	7.2	17.5	45.6	78.9	95.1
Density, (g/cm^3)	2.59					
Absorption of water, (%)	3.1					
Content of dust, mud, clay, (%)	1					
Modulus of magnitude	2.44					

2.4. Fly ash

Fly ash used is Pha Lai thermal fly ash with mechanical properties meeting technical requirements according to TCVN 10302-2014: density 2.16 g/cm^3, the activity index at 7 days is 79.8%, at 28 days is 84%.

2.5. Superplasticizer

Superplasticizer is used for the purpose of reducing the ratio of water to the cement in the concrete mix, while at the same time ensuring easy workability for the concrete mixture. In this study, the naphthalene formaldehyde sulfonate-based superplasticizer, the commercial name Sikament NN of Sika Vietnam, was investigated. This additive has some properties as follows:

- Product form: liquid;
- Color: dark brown;
- Volume mass 1.19-1.22 kg/liter;
- Content of chloride ion: not available
- Dosage: 0.60-2.00 liter/100 kg of cement

2.6. Crushed rubber flakes/beads

The crushed rubber flakes/beads used in research are recycled products from waste rubber, consisting of two-particle size groups: (1) Small grain group (particle size 1.25-5 mm), used to replace a small aggregate (sand), most of which have complex shapes, angled grains; rough, rough grain surface state. The commercial form is the rubber seed for artificial turf football fields. (2) Large grain group (particle size 5-15 mm), used to replace a large aggregate (crushed stone); relatively uniform particle shape, mostly rectangular or cube-shaped, relatively smooth and flat surface. This type is recycled from waste automotive tires by removing the reinforcement fiber in the tire and retaining the rubber component, splitting it into long threads, cutting with a cutter or by hand at ambient temperature. The recycling process and product of rubber flakes/beads are shown in Figure 1 and Table 4.

Table 4. The physical and mechanical properties of the recycled rubber flakes/beads

Items	**Large particle**			**Small particle**		
Particle size, mm	10-15	5-10	2.5-5	5-10	2.5-5	1.25-2.5
Content, (%)	95.8	4.2	0	19.2	74.5	6.3
Absorption of water, (%)	0.6			3.7		
Density (g/cm^3)	1.1					

Figure 1. Recycled rubber particles

2.7. Research Methods

With the goal of fabricating concrete grade M20-M30, in this paper, we used the absolute volume method, calculating, selecting, and adjusting the concrete composition on the basis of CP1 gradation (grade M60 concrete). The grades of concrete use the same type of cement, crushed stone, sand, rubber flakes/beads, additives, and water. The grades of concrete Cs10.10, Cs20.20, Cs25.25 replace the rubber flakes/beads and replace the small and large aggregates with the volume ratio of 10%, 20%, 25% compared to grade CP1 distribution. Although the amount of water mixed, and the ratio of water to the cement changes, but still ensures the slump of the concrete mixture about 12.5-14 cm. The composition of concrete is shown in Table 5.

Table 5. Composition of concrete mix

The grades of concrete	Cement (kg)	Water (kg)	Sand (kg)	Crushed stone (kg)	Small rubber (kg)	Large rubber (kg)	Fly ash (kg)	Superpla-sticizer (kg)	Rubber replacement rate by volume	
									% Sand	% Stone
CP1	382	148	659	1165	0	0	42	6.11	0	0
Cs10.10	382	145	593	1049	28	48	42	6.11	10	10
Cs20.20	382	125	527	932	56	96	42	6.11	20	20
Cs25.25	382	115	494	874	70	120	42	6.11	25	25

The compressive strength of concrete is determined on a 100x100x100 mm cube; modulus of elasticity under static compression is determined on a sample of 150x300 mm cylinders.

3. Results and discussion

3.1. Workability of concrete mixes

The workability of the concrete mixture is assessed according to the slump with the Abram test cone, according to the TCVN 3106:1993 standard. The results are shown in Figure 2.

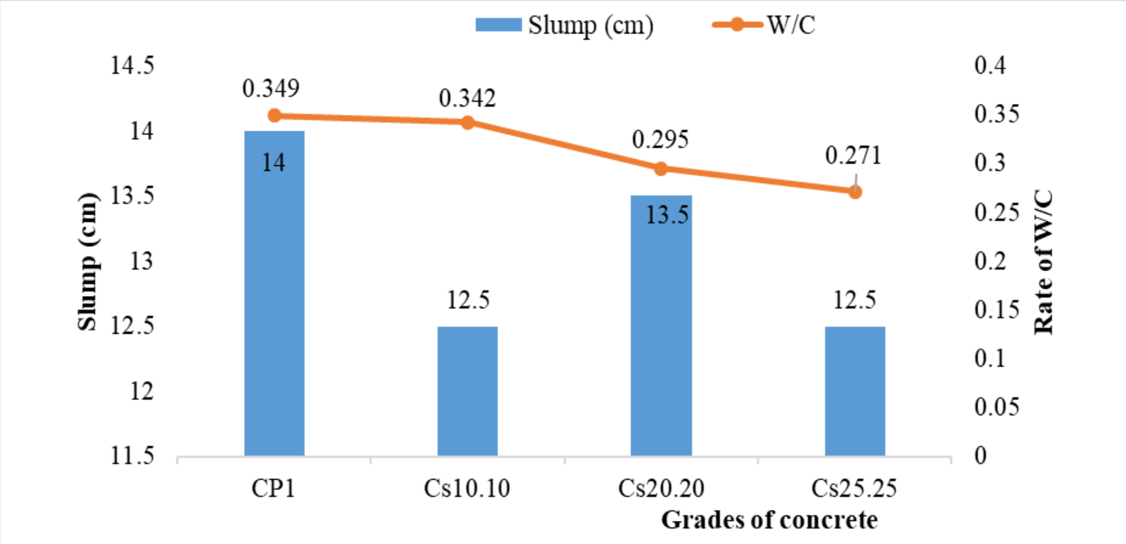

Figure 2. Slump of the tested concrete mixes

Experimental results show that the use of rubber to replace aggregate in general will significantly affect the workability of the concrete mixture (CM) or the ratio of W/C. In this study, the author adjusted the concrete composition to ensure that the slump of the CM was relatively stable in the range of 12.5-14 cm, the W/C ratio would decrease significantly. The more rubber used, the lower ratio of W/C is. At grade concrete Cs25.25 (rubber replacement rate up to 50% of aggregate volume) recorded a reduction of the W/C ratio to 0.271. This is a very low ratio compared to conventional concrete, contributing to ensuring the highest degree of consistency in the part of the concrete structure without rubber. The effect of increasing the ductility of concrete mixes when using rubber aggregates instead may be due to the rubber particles having less water absorption compared to natural aggregates. The smoother surface, together with using in the suitable ratio can increase the flexibility of the concrete mix. At the same time, the presence of fly ash also helps reduce the use of superplasticizers while improving the slump of the concrete mix. This is consistent with previous research works [13, 14].

3.2. Compressive strength of concrete

Experiments were conducted to determine the compressive strength of concrete according to TCVN 3118-1993 (Figure 3 and Figure 4); Results of average compressive strength of 3 test samples for each grade of concrete are shown in Table 6 and Figure 5.

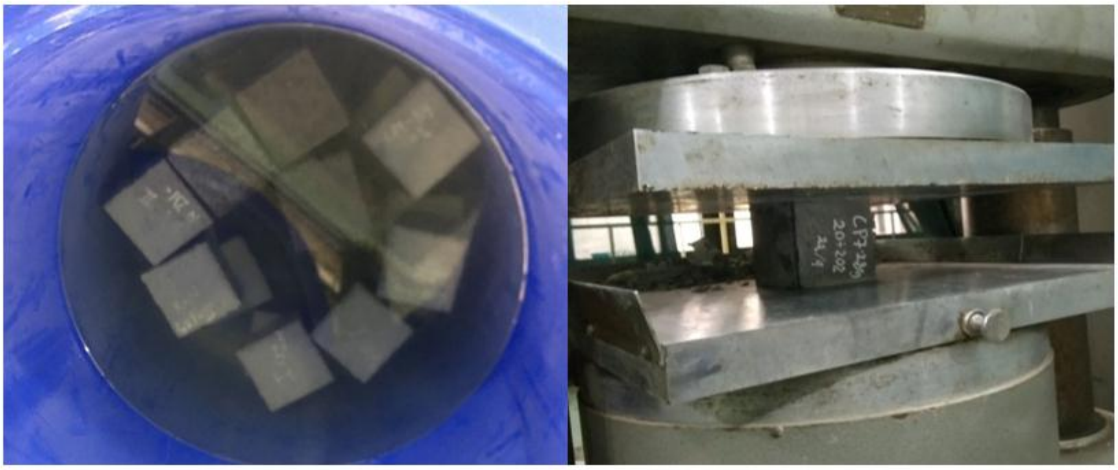

Figure 3. Test to determine compressive strength of concrete

Table 6. Variation of compressive strength of concrete over time

The grades of concrete	**Compressive strength (MPa)**			
	7 days	14 days	28 days	180 days
CP1	41.5	54.6	60.1	67.8
Cs10.10	25.5	31.4	34.1	42.4
Cs20.20	22.1	26.1	27.3	37.9
Cs25.25	20.6	21.6	22.5	28.9

Figure 4. Test of compressive strength of concrete

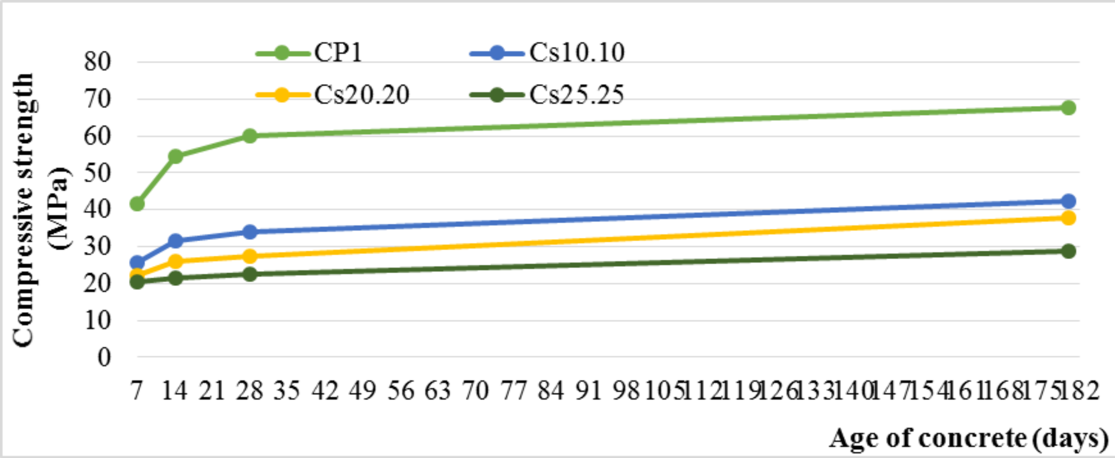

Figure 5. Variation of compressive strength of concrete over time

From the experimental results, it can be seen that when using crushed rubber flakes/beads from waste automobile tires to replace a small part of an aggregate and large aggregate, concrete M20, M30 can be completely fabricated. This has great significance in making use of waste materials, adding raw materials to make concrete, contributing to the goal of environmental protection and sustainable development.

Observing the strength development of the concrete without using rubber flakes/beads and the three types using rubber aggregates instead of aggregates found that the strength development is similar, the strength mainly develops in the first 28 days and the intensity tends to increase in the following days.

3.3. The static modulus of elasticity

The static modulus of elasticity of concrete is determined according to ASTM-C469 (Figure 6). Experimental results are shown in Figure 7.

Figure 6. Test of static elastic modulus of concrete

Table 7. The static elastic modulus of concrete

The grades of concrete	The static elastic modulus (GPa)	Compare with a grade of CP1 concrete (%)
CP1	41.5	100
Cs10.10	37	89
Cs20.20	31.6	76
Cs25.25	19.8	48

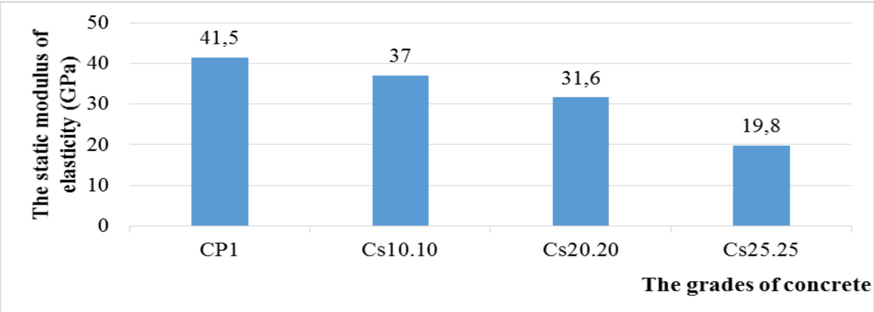

Figure 7. The static modulus of elasticity of concrete

By comparing the static elastic modulus results, we can see that when the rubber content increases, the elastic modulus decreases significantly. When the total percentage of replacement rubber is 10%, 20%, and 25% of the total volume of aggregate, the static elastic modulus is only 89%, 76%, 48% of the grade of concrete without using rubber, respectively. This shows that increasing the rate of replacement rubber to a certain extent may cause elastic deformation of the concrete to increase with the increase in the use of rubber. In particular, the amount of rubber replaced from 20% to 25% for each type of aggregate significantly reduced the elastic modulus of the concrete by 50% compared with the control aggregate.

4. Conclusions

From the obtained results, some conclusions are drawn as follows:

- Using the flakes/granules from waste rubber to replace at the same time a small aggregate and a large aggregated can completely make concrete M20, M30.

- The strength development of the test concrete is no different from that of conventional concrete.

- The use of rubber flakes/granules to replace at the same time a small and large aggregate with a reasonable ratio, combined with the use of fly ash will reduce the use of superplasticizers and still have the effect of improving ductility of concrete mixes.

- The presence of a rubber flakes/granules that partially replaces the aggregate effectively reduces the static elastic modulus of the concrete.

5. Suggestions

- Continue to study to improve the replacement rate, as well as completely replace natural aggregates with rubber pieces/particles crushed from waste tires made of concrete with grades lower than M20 or higher than M30.

- Study on damping and explosion energy consumption of concrete using waste rubber aggregate in buildings subjected to explosive loads.

References

[1] Ministry of Construction (2000), *Technical instruction for selecting concrete components of all kinds*, Construction Publishing House, Hanoi.

[2] Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression- ASTM C469.

[3] Chang Ni-Bin (2008), "Economic and policy instrument analyses in support of the scrap tire recycling program in Taiwan," *Journal of Environmental Management*, 86, 435-450.

[4] Jang Ji-Won, Yoo Taek-Soo, Oh Jae-Hyun, Iwasaki Iwao (1998), "Discarded tire recycling practices in the United States, Japan and Korea," *Resources, Conservation and Recycling*, 22, 1-14.

[5] Skripkiunas G, Grinys A, Cernius B (2007), "Deformation properties of concrete with rubber waste additives," *Mater Sci* 13:219-23.

[6] Aiello M, Leuzzi F (2010), "Waste tyre rubberized concrete: Properties at fresh and hardened state," *Waste Manage* 30:1696-704.

[7] Bignozzi M, Sandrolini F (2006), "Tyre rubber waste recycling in self-compacting concrete," *Cem Concr Res* 36:735-9.

[8] Topçu I, Demir A (2007), "Durability of rubberized mortar and concrete," *J Mater Civ Eng* 19.

[9] Albano C, Camacho N, Reyes J, Feliu J, Hernández M (2005), "Influence of scrap rubber addition to Portland concrete composites: destructive and non-destructive testing," *Compos Struct* 71:439-46.

[10] Balaha M, Badawy A, Hashish M (2007), "Effect of using ground waste tire rubber as fine aggregate on the behaviour of concrete mixes," *Indian J Eng Mater Sci* 14:427-35.

[11] Cairns R, Kew H, Kenny M (2004), *The use of recycled rubber tyres in concrete construction*, Final Report, The Onyx Environmental Trust, University of Strathclyde, Glasgow.

[12] Ghaly A, Cahill J (2005), "Correlation of strength, rubber content, and water to cement ratio in rubberized concrete," *Can J Civil Eng* 32:1075-81.

[13] Guneyisi E, Gesoglu M, Ozturan T (2004), "Properties of rubberized concretes containing silica fume," *J Cem Concr Res* 34:2309-17.

[14] Guneyisi E (2010), "Fresh properties of self-compacting rubberized concrete incorporated with fly ash," *Mater Struct*.

[15] Skripkiunas G, Grinys A, Cernius B (2007), "Deformation properties of concrete with rubber waste additives," *Mater Sci* 13:219-23.

[16] Turatsinze A, Garros M (2008), "On the modulus of elasticity and strain capacity of selfcompacting concrete incorporating rubber aggregates," *Resour Conserv Recycl* 52:1209-15.

NGHIÊN CỨU SỬ DỤNG SẢN PHẨM NGHIỀN TỪ CAO SU PHẾ THẢI THAY THẾ MỘT PHẦN CỐT LIỆU TRONG SẢN XUẤT BÊ TÔNG XI MĂNG

Tóm tắt: *Bài báo trình bày một số kết quả và quá trình nghiên cứu sử dụng sản phẩm nghiền từ cao su phế thải để thay thế một phần cốt liệu nhỏ và cốt liệu lớn trong chế tạo bê tông xi măng. Hỗn hợp hạt cao su được phân loại theo nhóm kích thước hạt, tương ứng với kích thước hạt cốt liệu cần thay thế. Sau đó đó tiến hành thay thế đồng thời cốt liệu nhỏ và cốt liệu lớn bởi hạt cao su với những tỷ lệ khác nhau. Kết quả nghiên cứu cho thấy hoàn toàn có thể chế tạo được bê tông xi măng mác M20 - M30 khi thay thế từ 10-25% thể tích cốt liệu bằng hỗn hợp cao su có kích thước hạt tương đương. Điều này có ý nghĩa lớn trong việc tìm kiếm nguồn nguyên liệu thay thế để chế tạo bê tông, nhằm giảm khai thác tài nguyên thiên nhiên, góp phần hạn chế ô nhiễm môi trường và hướng đến mục tiêu phát triển bền vững.*

Từ khóa: Hạt cao su tái chế; cao su phế thải; thay thế cốt liệu; bê tông; phát triển bền vững.

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