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Deformation Properties of Concrete with Rubber Waste Additives

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The aim of investigation was to study the deformation properties of Portland cement concrete with rubber waste additive. Concrete mixtures with the same compressive strength as concrete without this additive were tested. Used tires rubber wastes were crumbed into fraction 0/1. The rubber additive was used as fine aggregate replacement in concrete mixtures by 3.2 % of aggregates mass. The effect of rubber waste additive on technological properties, air content in fresh concrete, density and deformation properties under the static and dynamic load of concrete was investigated.

Keywords: Portland cement concrete, rubber waste additive, compressive strength, deformation properties, modulus of elasticity, dynamic modulus of elasticity, cyclic load, strain, stress-strain diagram.

1. INTRODUCTION

Big amounts of used rubber tyres cumulate in the world each year – 275 million in the United States [1] and about 180 million in European Union [2]. One of the most popular methods is to pile used tyres in landfills, as due to low density and poor degradation they cannot be buried in landfills [3]. These tires can also be placed in a dump, or basically piled in a large hole in the ground. However these dumps serve as a great breeding ground for mosquitoes and due to the fact that mosquitoes are responsible for the spread of many diseases, this becomes a dangerous health hazard [4]. In industry higher amounts of rubber tyre waste can be utilized as fuel, pigment soot, in bitumen pastes, roof and floor covers, and for paving industry [2, 5, 6].

One such application that could use old rubber tires is rubberized concrete. Concrete can be made cheaper by replacing some of its fine aggregate with granulated rubber crumbs from used rubber tires. These granulated rubber crumps are achieved through a process called continuous shredding, which is necessary to create crumbs small enough to replace an aggregate as fine as sand. Such kind of concrete is used in manufacture of reinforced pavement and bridge structures have better resistance to frost and ice thawing salts [5, 7, 8].

The replacement of aggregates with granulated rubber waste deteriorates mechanical properties of concrete [9 – 12]. The decrease of compressive strength of concrete after modification with rubber waste is explained by the more elastic and softer rubber particles compared to the sand particles [1, 9 – 12]. The second reason for concrete compressive strength reduction is significantly lower compressive strength of the crumbed rubber particles comparing to the strength of concrete aggregates [13, 14]. Deterioration of the mechanical properties of concrete with rubber additives is also explained by low adhesion among the rubber particles and cement matrix [2, 15]. However as it is observed in [6, 16], there is a strong adhesion of contact zone between rubber the particles and cement matrix, therefore this presumption should be rejected. Most compressive strength reduction was observed in concrete mixtures with 0/1 fraction tyres rubber waste additive (20 %) [7, 8].

Using rubber waste in concrete, less concrete module of elasticity is obtained [1, 6, 17, 18] therefore modulus of elasticity is related to concrete compressive strength and the elastic properties of aggregates have substantial effect on the modulus of elasticity of concrete. The larger amount of rubber additives is added to concrete, the less modulus of elasticity is obtained [1, 17].

The objective of the work was to analyze the effect of fine composition of the elastic aggregate made from rubber waste on the elastic properties of concrete under the static and dynamic load.

2. EXPERIMENTAL

2.1. Test methods

Dry aggregates were used for the concrete mixtures under research. Cement and aggregates were batched by weight while water and chemical mixtures were batched by volume. Chemical admixtures in the form of solutions were mixed with water used in preparation of concrete mixtures. Concrete mixtures were mixed for 3 minutes in the laboratory in a forced type concrete mixer.

The consistency, density and air entraining of concrete mixture were determined by EN 12350-2, 12350-6 and 12350-7. Concrete specimens – prisms $(100 \times 100 \times 300)$ mm were cured in conditions according EN 12390-2 and tested after 28 days. Density of concrete was determined by EN 12390-7, compressive strength – by EN 12390-3.

Static modulus of elasticity was determinate according ISO 6784. Along deformations of the specimen were measured by a transducer. Transducer for the longitudinal deformations measurement was attached on a special frame. The specimen was loaded until $f_c/3$, were f_c is the concrete prismatic compressive strength. Specimens were

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loaded for 3 cycles by 0.6 N/mm^2 ±0.4 N/mm^2 speed for the elimination of plastic strain. The force in top limit of cycles was held 30 s. After 3 precycles static modulus of elasticity E_c, N/mm^2 was calculated by:

$$E_c = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{(\sigma_a - \sigma_b)}{(\varepsilon_a - \varepsilon_b)}; \quad (1)$$

where: σ_a is the normal stress, $\sigma_a = f_c / 3$, N/mm^2; σ_b is the normal stress, $\sigma_b = 0.5$ N/mm^2; ε_a is the strain on σ_a stress; ε_b is the strain on σ_b stress.

Dynamic modulus of elasticity was determined according to the resonant frequency of vibration enhancing the flexural stress:

$$E_{din} = 0.965 \cdot 10^{-3} (\frac{l}{h})^3 \frac{Pf^2}{b} \cdot T, \text{ kG/cm}^2; \quad (2)$$

where: l is the length of sample, cm; b is the width of sample, cm; h is the height of sample, cm; f is the resonant frequency, Hz; T is the coefficient depending on the ratio h/l ($T = 1.38$, for $h/l = 0.33$).

After evaluation the geometrical parameters, the resonant frequency of oscillation was measured. A form of resonant curve was applied and logarithmic decrement of fluctuations δ, Hz was calculated:

$$\delta = \frac{\pi}{\sqrt{3}} \frac{f_2 - f_1}{f_0}; \quad (3)$$

where: f_1 is the frequency after resonance, when amplitude is two times lower than resonance Hz; f_2 is the frequency before resonance, when amplitude is two times lower than resonance Hz; f_0 is the resonance frequency Hz.

Concrete prisms $(100 \times 100 \times 300)$ mm were loaded by cyclic stress in testing machine. Specimens were loaded with compressive strain by 1 N/mm^2 speed. All specimens were loaded with the same number of cycles – 20. For all specimens bottom limit of cycles was the same – 5 kN. The force in bottom limit of loading was held 10 seconds. Top limit of loading was selected 70 percents, 80 percents and 90 percents of the specimens prismatic strength. The force in top limit of loading was held 20 seconds. After the cycles the specimens were loaded until failure.

2.2. Used materials

Concrete mixtures with and without rubber wastes with the same compressive strength were prepared in this work. W/C ratio to get similar compressive strength for the concrete with rubber waste compare with concrete without rubber waste was calculated: 0.55 – for the concrete without rubber; 0.45 – for the concrete with 0/1 fraction tyres rubber waste.

Portland cement CEM I 42.5R was used for investigation. Water content for normal consistency cement slurry 24.5 percent, fineness of cement – 371 m^2/kg.

The fine aggregate was used sand fr. 0/4. Part of sand was replaced by rubber waste from used tires. The coarse aggregate was used crushed gravel fr. 4/16. Coarse aggregate content in all concrete mixtures was the same – 995 kg for the one cubic meter of concrete. Plasticizing admixture based on policarboxile polymers was used with density of solution 1040 kg/m^3. In all mixtures content of plasticizing admixture was the same – 0.6 percent from cement content.

Mechanically crumbed rubber waste from used tires was used. Rubber waste was classificated to fraction 0/1. The technological equipment for used tires rubber waste processing is installed in JSC "Metaloidas" Šiauliai, Lithuania. The density of crushed rubber waste particles is 1020 kg/m^3, bulk density – 483 kg/m^3.

3. RESULTS AND DISCUSSION

In order to examine the effect of crumbed rubber waste, the damper additive of concrete, on the characteristics of concrete mixture and elastic properties of concrete, two concrete mixtures tested: concrete mixture without rubber additive and concrete with 0/1 fr. rubber additives. 3.2 percent from the aggregate of rubber waste was used in concrete mixture (Table 1).

3.1. Characteristics of concrete mixtures

The slump, density and entrained air content was obtained in this study. It was determined that 0/1 fr. rubber additives 3.2 percent from aggregate effects the properties of concrete mixtures. Properties of the mixtures are shown in Table 2.

It was obtained that rubber waste additive has no influence on the slum of concrete mixture (Table 2), while the results showed that density of concrete mixture decreased (from 2396 kg/m^3 to 2380 kg/m^3) when using elastic additive from tires rubber waste (Table 2). Entrained air content increased (from 3 % to 3.5 %) in concrete mixtures with addition of tires rubber waste particles (Table 2). Lower density of concrete mixture with rubber waste is explained due to less density of rubber waste particles compared with fine aggregate – sand particles density. Concrete mixtures density reduction with addition of rubber waste particles 3.2 percent for the concrete with equal strength.

The increasing of air entraining of concrete mixtures with rubber waste additive can be explained by higher porosity of the rubber waste particles than sand particles and very porous surface of rubber particles.

Table 1. Proportions of concrete mixtures

Rubber waste fraction	Materials content for 1 m^3 of concrete mixture					
	Rubber waste, kg	Cement, kg	Crushed gravel 4/16, kg	Sand 0/4, kg	Superplastycizer, %	Water, l
0/1	23.13	404	995	723	1.98	182
–	–	330	995	891	1.98	182

Table 2. Properties of concrete mixtures and hardened concrete

Concrete properties	Concrete mixture slump, cm	Air entrainment, %	Concrete mixture density, kg/m^3	Prismatic compressive strength, MPa	Density, kg/m^3	Modulus of elasticity, GPa	
						static	dynamic
With rubber additive	19	3.6	2380	43.84	2342	29.58	37.04
Without rubber additive	19	3.0	2396	44.49	2362	33.17	37.98

3.2. Properties of hardened concrete

Dependence of concrete prismatic compressive strength on the concrete with and without rubber waste additive is shown in Table 2. From this table it can be seen that investigated concrete prismatic compressive strength did not change.

Density of the hardened concrete is shown in Table 2. It was obtained lower density in hardened concrete with rubber waste additive than concrete without rubber waste additive. Reduction of concrete density is the same range like concrete mixture density reduction with addition of rubber particles (Table 2).

Concrete static modulus of elasticity for investigated specimens is shown in Table 2 and stress-strain relationship during the specimens loading – in Fig. 1 and 2.

Fig. 1. Stress-strain relationship for concrete without rubber waste

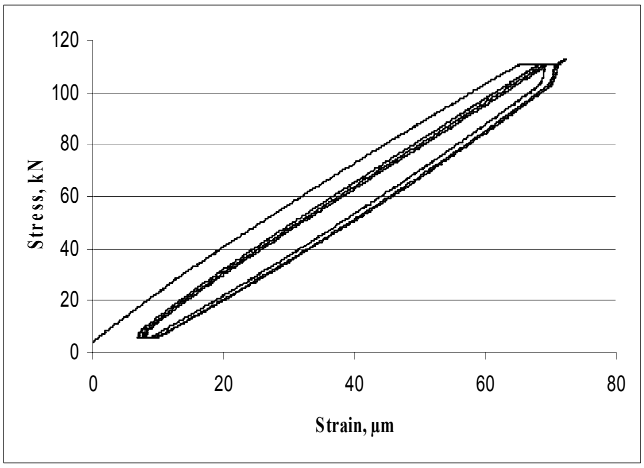

Fig. 2. Stress-strain relationship for concrete with rubber waste

It was obtained that rubber additives reduced static modulus of elasticity. The average static modulus of elasticity is 33.2 GPa in concrete without rubber additives and the 11 % higher than that in products where rubber waste was used (29.6 GPa). The addition of rubber particles is effective mean for reduction of concrete modulus of elasticity and increasing deformability of concrete. From the Figs. 6 and 7 it was obtained that concrete without rubber waste deformations on $f_c / 3$ load after 3 cycles varies from 54.9 µm to 58.8 µm while concrete with elastic additive – from 64.6 µm to 71.1 µm.

Table 2 presents the dynamic modulus of elasticity defined by a resonant method. It can been seen, using rubber waste in concrete the dynamic modulus of elasticity decreased only 1 % – 2 % comparing without rubber additives

The reduced both static and dynamic modulus of elasticity in concrete with waste rubber aggregates may be explained by low modulus of elasticity of small rubber particles, which is much lower than fine aggregate – sand modulus of elasticity [19].

The specimens deformation curves after cyclic loading according to procedures described in section 2 are presented in Figs. 3 – 6.

It was obtained that concrete specimens without rubber waste additive strains after loading to 70 percent of prism compressive strength is 736 µm while concrete specimens with rubber waste additive after the same loading is about 1199 µm. The increasing of strain after 20 cycles of loading to 70 percent of prism compressive strength is about 217 µm for concrete without rubber waste and 162 with rubber waste additive. Load shedding strains for concrete with and without rubber waste varies from 164 µm to 264 µm and from 547 µm to 661 µm.

The specimens stress-strain relationship after loading of 80 percents of prism compressive strength are presented in Figs. 3 and 4.

The similar tendencies were observed of concrete deformations from the prismatic compressive strength with increasing the loading. With increasing load up to 80 percent of the prismatic compressive strength the specimens with no tyres rubber waste additive, longitudinal strains varies from 743 µm in the first cycle to 880 µm after 20 cycles. Load-shedding strains varies from 85 µm on first cycle to 191 µm after 20 cycles. While using damping elastic additive on load strains varies from 1161 µm to 1434 µm, while unload strains – from 391 µm to 642 µm.

The specimens deformation curves after loading of 90 percents of prism compressive strength are presented in Figs. 5 and 6.

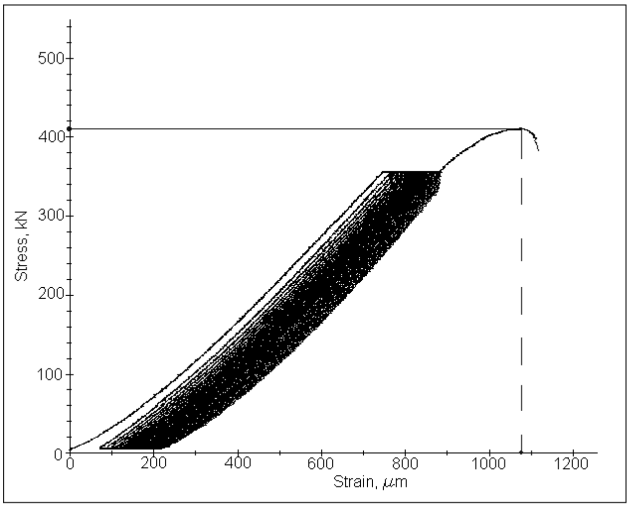

Fig. 3. Stress-strain relationship of the concrete without rubber waste additive after 20 cycles loading 80 percent of compressive strength

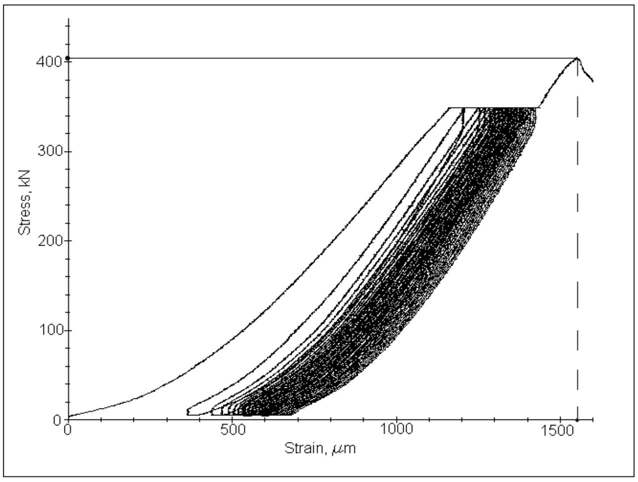

Fig. 4. Stress-strain relationship of the concrete with rubber waste additive after 20 cycles loading 80 percent of compressive strength

It was obtained, that concrete specimens without rubber waste as rubberized specimens sustained 20 cycles. Non rubberized concrete specimens after loading strains varies from 743 µm to 955 µm, while load-shedding strains varies from 140 µm to 271 µm meanwhile concrete specimens with elastic additive from tyres rubber waste after loading strains varies from 1213 µm to 1467 µm, and unload strains varies from 446 µm to 656 µm.

The results showed that the tyres rubber waste additives have great influence on concrete deformability after loading as under set loading. Deformations after loading of 70 % of prism compressive strength on concrete with elastic additive from tyres rubber waste are 63 % higher, while set deformations – 234 % higher than none rubberized concrete. Specimens with tyres rubber waste additive with increased load to 80 percent of prism compressive strength deformations accordingly 56 % and 360 % higher than specimens with no rubber waste additive. The rubberised specimen's deformation results with load of 90 percents of prism compressive strength are 63 % and 219 % higher than none rubberised specimens.

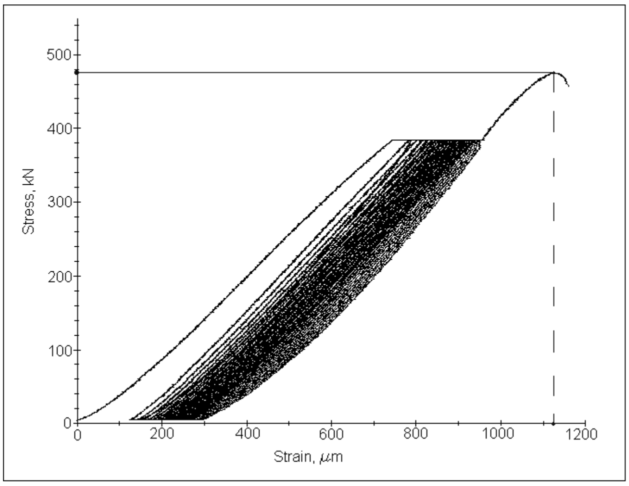

Fig. 5. Stress-strain relationship of the concrete without rubber waste additive after 20 cycles loading 90 percent of compressive strength

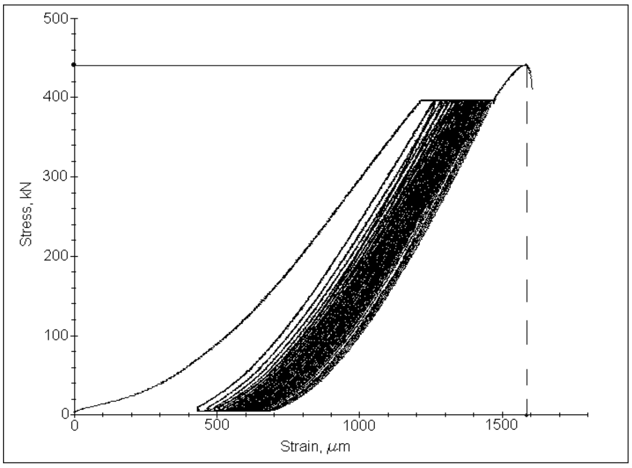

Fig. 6. Stress-strain relationship of the concrete with rubber waste additive after 20 cycles loading 90 percent of compressive strength

It was obtained that 20 cycles of loading to 70, 80 and 90 percent of prism compressive strength have no influence on concrete strength for both concrete mixtures with and without rubber waste additive (Fig. 7).

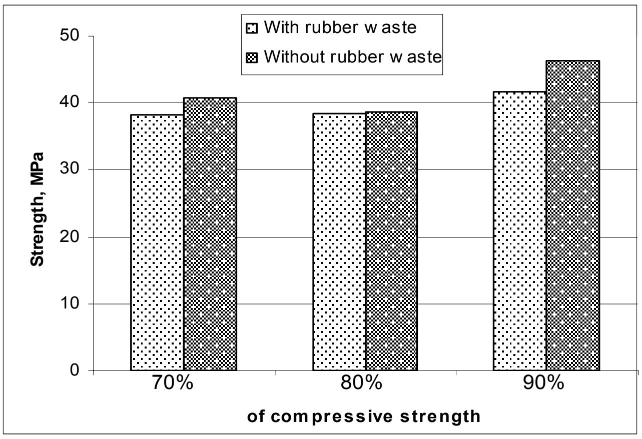

Fig. 7. Strength of concrete with and without rubber waste additive after 20 cycles loading 70, 80, 90 % of compressive strength

While concrete ultimate strains on failure are on significant effect form the tire rubber waste additive. Ultimate strain of concrete with elastic additive is 32 % higher when the cyclic loading up to 70 % was obtained, 44% higher when the loading was up to 80 % and 42 % when the loading was up to 90 % than specimens with no rubber waste additive (Fig. 8).

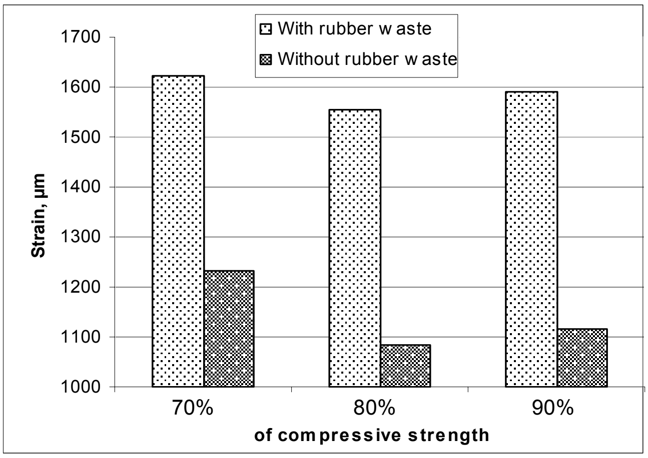

Fig. 8. Ultimate strains on failure of concrete with and without rubber waste additive after 20 cycles loading 70, 80, 90 percent of compressive strength

From deformation curves in Figures 3 – 6 can be seen that the specimens with no tyres rubber waste deformations with the increasing the stress are almost straightly. Strains of the concrete with tires rubber in the beginning of stress increasing are higher comparing with the concrete without rubber waste. It can be explained by the great deformability of rubber waste particles under the low loads. Most of these deformations of rubber waste particles have plastic nature. Therefore concrete with tire rubber waste has higher set deformations than non rubberised concrete.

4. CONCLUSIONS

1. Rubber waste additives reduced both static and dynamic modulus of elasticity.
2. Strains of the concrete with the same compressive strength with rubber waste from used tires (3.2 percent from aggregate by mass) deformations are 56 % – 63 % higher after the static loading, while set deformations after the unloading is 219 % – 360 % higher than for the none rubberised concrete.
3. Cyclic loading of 20 cycles have no influence on the prismatic compressive strength of both concrete with and without rubber waste (3.2 percent from aggregate by mass).
4. Ultimate strains on concrete failure load are 36 % – 47 % higher for concrete with tyre rubber waste additive.

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