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Damping Properties of Concrete with Rubber Waste Additives

Gintautas SKRIPKIŪNAS[1*], Audrius GRINYS[2], Kęstutis MIŠKINIS[2]

[1]*Building Materials and Structures Research Centre, Kaunas University of Technology, Studentų 48, LT-51367 Kaunas, Lithuania*
[2]*Department of Building Materials, Kaunas University of Technology, Studentų 48, LT-51367 Kaunas, Lithuania*

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The aim of this research was to investigate the damping properties of hardened concrete with rubber waste additives. Mixtures: one without rubber waste additives (control specimen) and mixtures with different fraction (0/1; 1/2; 2/3) and different amount (5 %; 10 %; 20 %; 30 % from fine aggregate (sand) mass) of rubber waste additives. The influence of rubber waste additive on hardened concrete damping characteristics and strength properties were evaluated. Compressive and flexural strength of concrete decrease with increasing tires rubber waste additive amount was obtained in this study. The addition of rubber waste to concrete decreased the dynamic modulus of elasticity but increased damping decrement of the concrete. The amount of rubber waste had more noticeable effect on concrete damping properties than particles size distribution.

Keywords: damping properties, rubber waste additives, concrete.

1. INTRODUCTION

The noise in our life has become very crucial and complex problem of late years. Noise from neighbours is one of the common problems the indoor environment in dwellings. Propagation and radiation of sound of shoes of walking persons or playing children on floors, musical instruments and audio systems, technical equipment with moving components, water valves and pipes rigidly connected to walls or floors, people activities have been considered as an increasing problem in buildings [1 – 4]. The sound, which travels through buildings structure, is called structure-borne noise. Most of buildings are constructed of solid material – concrete. The structure-borne noise is low-frequency noise and has feature to travel long distances from source in solid materials. It can be radiated as audible sound even in rooms far from the source [2]. Noise emissions with predominant low-frequency sound components may exert considerably disturbing effects in dwellings [5].

Another problem that is topical in today's world is environment pollution. The people's activities create a lot of different waste every year. The used car tyres are one of frequent problems. All over the world, the amount of rubber waste has gradually increased in the recent years [6]. Every year the number of used tires grows very quickly for example only in EU nations is estimated that each year about 180 million rubber tyres cumulate [7]. With the disposal of an estimated 270 million vehicle tires each year in the United States are generated. According to this amount 15 million of the 270 million scrap-tires generated yearly are exported, 10 million are recycled into new products, 20 million are processed into ground rubber, 125 million are used as tired-derived fuel and 30 million in civil engineering applications [8].

These two problems can be solved together. Frequently to solve the problem of structure-borne noise is to use resilient materials as mineral wool, diverse foams, rubber or elastic polystyrene [9 – 12]. And the problem of used tires are settled by utilizing them. It is not always possible to use resilient materials for solving the problem of structure-borne noise and the utilizing of used tires is not the best solution. The solution of these two important problems of our time are can be found new look.

Especially structure-borne noise is topical problem in solid materials (monolithic frame) buildings. To solve the problem of damping and absorption of low-frequency noise in solid structures modified solid materials with better damping properties can be used. To characterize the damping properties of solid materials dynamic modulus of elasticity, quality factor and damping decrement are used. Damping is conversion of mechanical energy into heat during vibration or deformation of material. Elastic materials transform energy into heat effectively. New solid materials wich have better elastic features with having lower dynamic modulus of elasticity higher quality factor and damping decrement are investigated. Such materials will transform better mechanical energy into heat and will better damping properties of structure-borne noise. Suchlike new material could be concrete with rubber waste additives – elastic concrete [6, 8].

The use of crumb rubber and tire chips has found a lot of attention as rubber aggregates in the literature. The overall results indicated that the replacement of aggregates with granulated rubber waste deteriorates mechanical properties of concrete [13 – 15]. The use of coarse rubber particles affected the concrete properties more negatively than fine particles [17, 19, 21].

In this research hardened concrete with rubber waste additive was investigated. The concrete fine aggregate – sand was replaced with rubber waste additives.

The aim of this investigation was to evaluate the influence of recycled rubber waste additives on damping properties of hardened concrete. Damping properties of the concrete were evaluated by dynamic modulus of elasticity, quality factor and damping decrement. Compressive and flexural strength of hardened concrete was determined as well.

*Corresponding author. tel.: +370-37-455120; fax: +370-37-435324.
E-mail address: *gintautas.skripkiunas@ktu.lt* (G. Skripkiūnas)

Table 1. Proportions of concrete mixtures

Notation	RW fraction	Materials content for 1 m^3 of concrete mixture						
		Quantity of RW, %	RW amount, kg	Cement, kg	Sand 0/4, kg	Crushed gravel 4/16, kg	Chemical additive, kg	Water, l
NR	–	–	–	451	875	949	2.255	160
R 0/1_5	0/1	5	35.14	451	784	949	2.255	160
R 0/1_10		10	70.28		693			
R 0/1_20		20	140.55		510			
R 0/1_30		30	210.83		328			
R 1/2_5	1/2	5	35.14	451	784	949	2.255	160
R 1/2_10		10	70.28		693			
R 1/2_20		20	140.55		510			
R 1/2_30		30	210.83		328			
R 2/3_5	2/3	5	35.14	451	784	949	2.255	160
R 2/3_10		10	70.28		693			
R 2/3_20		20	140.55		510			
R 2/3_30*		30	210.83		328			

* none technological mixture.

2. MATERIALS AND SPECIMENS

In this research several different concrete mixtures are used: without rubber waste additive and concrete with different amount of rubber fraction and waste additive to determine the effect of crumbed rubber waste (RW) on hardened concrete properties.

Portland cement CEM I 42.5R by Lithuanian Akmenės Cementas, according European standard EN 197-1 was used in this research. Water content for normal consistency cement slurry was 24.5 percent, fineness of cement – 371 m^2/kg. As a fine aggregate 0/4 sand fraction was used. Part of the fine aggregate of this mixture was replaced by a rubber waste additive from the used tires (5, 10, 20 and 30 % from aggregate by mass). The coarse aggregate was used crushed gravel 4/16. Coarse aggregate content in all concrete mixtures was the same – 949 kg for the one cubic meter of concrete. In the mixtures plasticizing admixture 0.5 % from the cement content was used. The plasticizing admixture based on policarboxile polymers was used with density of solution 1040 kg/m^3.

Mechanically crumbed RW from the used tires was used in the mixtures. RW was classified to fractions 0/1, 1/2, 2/3 (from JSC “Metaloidas” Šiauliai, Lithuania) with density of 1021 kg/m^3. The characteristics of used tires rubber waste additives are presented in literature [22].

To determine the influence of crumbed rubber waste additive on the damping and strength properties of hardened concrete different mixtures were made under laboratory conditions: control mixture – not rubberized (NR) concrete and concrete with different size and amount rubber waste aggregate (R). As waste rubber aggregates three different groups of waste rubbers granule sized between the ranges of 0 – 1, 1 – 2 and 2 – 3 mm were used.

In waste rubberized concretes for determining modulus of elasticity, quality factor, damping decrement, flexural strength and compressive strength mixtures were prepared by using 0, 5, 10, 20 and 30 % of aggregate mass replacing part of sand by waste rubber. Proportions of the concrete mixtures are presented in Table 1.

For concrete mixture we found that using 2/3 fraction of 30% of rubber waste additive we lost homogeneity of concrete because of segregation of aggregates. From this reason concrete mixture notated R 2/3_30 was not used in the further experiments.

For concrete mixtures were produced in laboratory mixture. (100×100×100) mm cubes and (100×100×300) mm prisms specimens were casted in metal moulds. Concrete specimens were cured in conditions according EN 12390-2 and tested after 28 days.

To determine damping properties of hardened concrete for each mixture 6 pieces of (100×100×300) mm specimens (prisms) were made. Dynamic modulus of elasticity was measured using the Erudite MKIV Resonant Frequency Test System. Using this system resonance frequency and frequencies (f_1 and f_2 respectively) either side of resonant frequency (f_0) where the amplitude of vibration drops to 0.707 of the maximum value were measured. Using these measured frequencies, quality factor (Q) was calculated:

$$Q = \frac{f_0}{f_2 - f_1} \quad (1)$$

and damping decrement (δ):

$$\delta = \frac{\pi}{\sqrt{3}} \frac{f_2 - f_1}{f_0}. \quad (2)$$

To determine strength properties of the hardened concrete for each mixture 6 pieces of (100×100×100) mm (cubes) and 6 pieces of (100×100×300) mm (prisms) specimens were made. Properties of hardened concrete were determined: compressive strength by EN 12390-3 and flexural strength was measured by EN 12390-5. The universal test machine ToniTechnic 2020 was used for measurement of strength. The force measurement accuracy of this equipment is ±1 % and uncertainty of compressive strength measurement is 0.70 MPa.

3. RESULTS AND DISCUSSION

To evaluate the influence of rubber waste additives on damping properties of hardened concrete dynamic modulus of elasticity, quality factor, damping decrement were determined.

The results of dynamic modulus of elasticity of NR and R specimens are shown in Fig. 1.

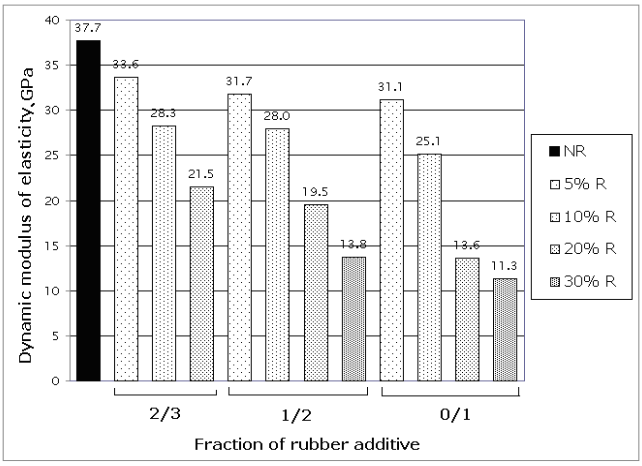

Fig. 1. Comparison of dynamic modulus of elasticity of concrete with different fraction of rubber additive

Fig. 1 shows that average dynamic modulus of elasticity of NR is 37.7 GPa. From Fig. 1 we see that increasing amount of rubber waste additives from 5 % to 30 % the dynamic modulus of elasticity decreases. The decrease is 15 % (5 % R), 28 % (10 % R), 52 % (20 % R) and 67 % (30 % R) respectively comparing with NR. The maximum decrease was obtained by using 30 % of 0/1 and 1/2 fraction of rubber (from 37.7 GPa to 11.3 GPa and 13.8 GPa respectively). The decrease is 70 % and 63 % respectively comparing with NR. Very similar decrease was determined by using 20 % of 0/1 fraction of rubber (64 % comparing with NR). The most significant decrease of dynamic modulus of elasticity was obtained by using 0/1 fraction of rubber waste than 1/2 and 2/3 (average 46 %, 38 % and 26 % accordingly). Decrease of dynamic modulus of elasticity is associated with internal damping and energy dissipation in material because concrete with rubber additives is more elastic than without.

The internal damping is better when quality factor is lower as possible. From Fig. 2 we see that the quality factor – *Q* decreases for concrete with rubber waste additives comparing with NR increasing rubber amount from 5 % to 30 %. The decrease is 12 % (5 % R), 17 % (10 % R), 28 % (20 % R) and 37 % (30 % R) respectively comparing with NR. The maximum decrease of quality factor comparing with NR was obtained by using 30 % of 0/1 and 1/2 fraction of rubber waste (from 23.44 to 15.47 and 14.08 respectively). The decrease is 34 % and 40 % respectively comparing with NR. Also from Fig. 2 we see that two values differs from others: using 5 % of 1/2 fraction was obtained 9.8 % less value than using 0/1 and 2/3 fraction of rubber and using 20 % of 2/3 fraction of rubber we got higher 14.9 % value than using 0/1 and 2/3. Decrease of quality factor is associated with decreasing of resonance frequency of R, Hz (Fig. 3).

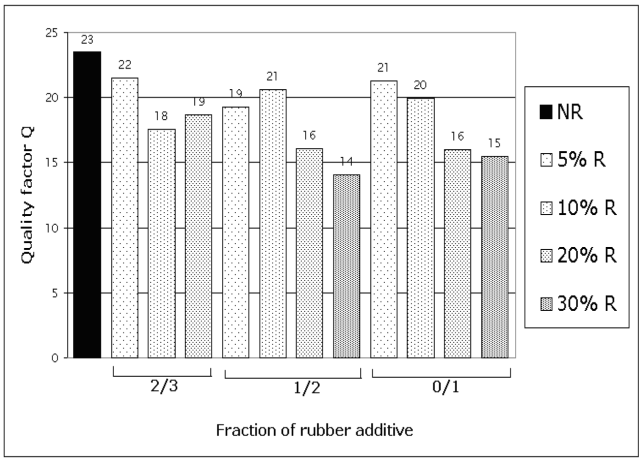

Fig. 2. Comparison of quality factor of concrete with different fraction of rubber additive

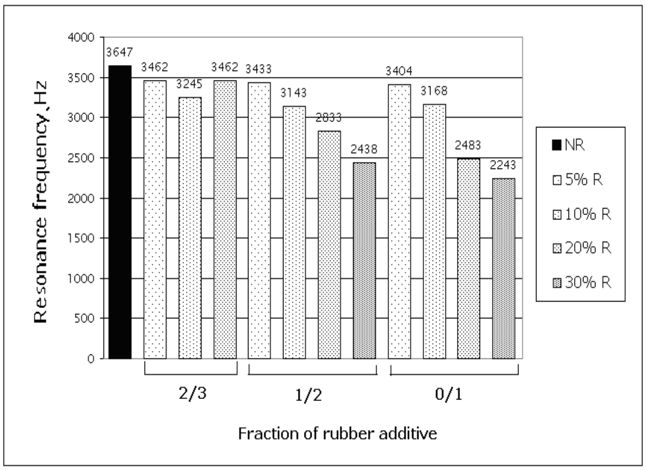

Fig. 3. Resonance frequency comparison of concrete with different fraction of rubber additive

From Fig. 3 we can see that rubber waste additives decreases resonance frequency of R comparing with NR. The resonance frequency of NR is 3647 Hz. The additives of rubber accordingly 5 %, 10 %, 20 % and 30 % it decreases to (3404–3462) Hz, (3143–3245) Hz, (2438–3462) Hz and (2243–2438) Hz respectively. The resonance frequency decrease is accordingly 5 % – 7 %, 11 % – 14 %, 5 % – 32 % and 33 % – 39 % comparing with NR.

The internal damping is better when damping decrement is high as possible. From Fig. 4 we see that damping decrement is 0.08 of NR. Increasing the amount of rubber waste additives the damping decrement increased average 15 % (5 % R), 24 % (10 % R), 39 % (20 % R) and 60 % (30% R) respectively comparing with NR. Also from Fig. 4 we see that using bigger amount of rubber additives of 0/1 and 1/2 fraction the damping decrement increased, but using 2/3 fraction it decreased 9 % (20 % R) comparing with 10 % R and using 10 % R of 1/2 fraction rubber it 9 % decreased comparing with 5 %.

The concrete damping properties (dynamic modulus of elasticity and damping decrement) with rubber waste additive were studied by other authors [23 – 27]. They also obtained that dynamic modulus of elasticity decreased and damping decrement increased when amount of rubber aggregates increased.

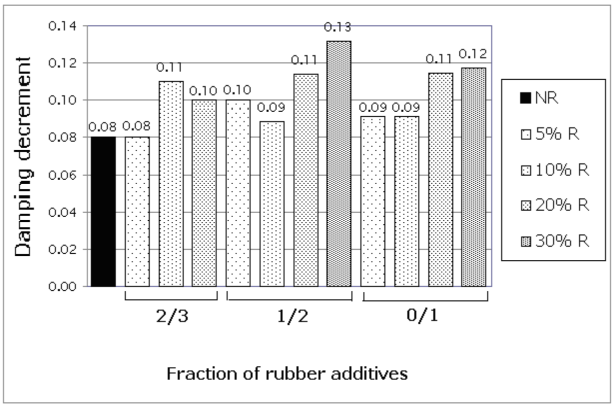

Fig. 4. Comparison of damping decrement of concrete with different fraction of rubber additive

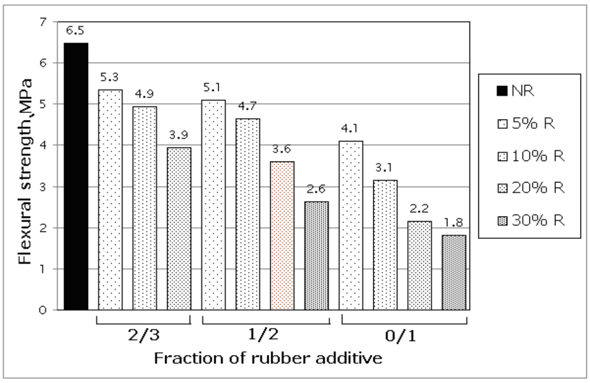

Fig. 5. Comparison of flexural strength of concrete with different fraction of rubber additive

Fig. 5 shows the effect of RW replacement on the flexural strength of concrete. It was obtained that RW reduces concrete flexural strength as more as RW particles amount increased. From Fig. 5 we see that none rubberized concrete average flexural strength is 6.5 MPa (standard deviation $\sigma = 0.22$ MPa), while concrete with finest rubber waste particles decreases flexural strength from 4.1 MPa ($\sigma = 0.30$ MPa) of using 5 percent RW amount to 1.8 MPa ($\sigma = 0.21$ MPa) using 30 percent of rubber waste amount. However comparing control specimen flexural strength with large fractions of RW (1/2 and 2/3) the same decrease was obtained. From Fig. 5 can be seen that fine aggregate replacement by RW fraction 1/2 of 5 percent amount decreases flexural strength by 21 % (5.1 MPa $\sigma = 0.24$ MPa). Using 10, 20 and 30 percent of RW 1/2 fraction and comparing to control specimen, flexural strength decreases 28 % (4.7 MPa $\sigma = 0.22$ MPa), 45 % (3.6 MPa $\sigma = 0.48$ MPa) and 60 % (2.6 MPa $\sigma = 0.11$ MPa) respectively. Meanwhile coarse rubber waste aggregate (fraction 2/3) comparing to none rubberized concrete decreases flexural strength by 18 % (5.3 MPa $\sigma = 0.32$ MPa), 24 % (5.0 MPa $\sigma = 0.16$ MPa) and 39 % (3.9 MPa $\sigma = 0.36$ MPa) increasing quantity of rubber waste 5, 10, 20 % accordingly.

Fig. 6 shows the effect of the different fraction and different amount tires rubber waste particles comparing to none rubberized specimens on the flexural strength of concrete at 28 days. As the experimental results demonstrate, use of RW in concrete causes a decrease in flexural strength by polynomial trend. Flexural strength regression equations and the multiple regression correlation coefficients of specimens are shown in Fig. 6. It can be seen that correlation coefficient value varies from 0.97 to 0.98 respectively to the rubber waste fraction.

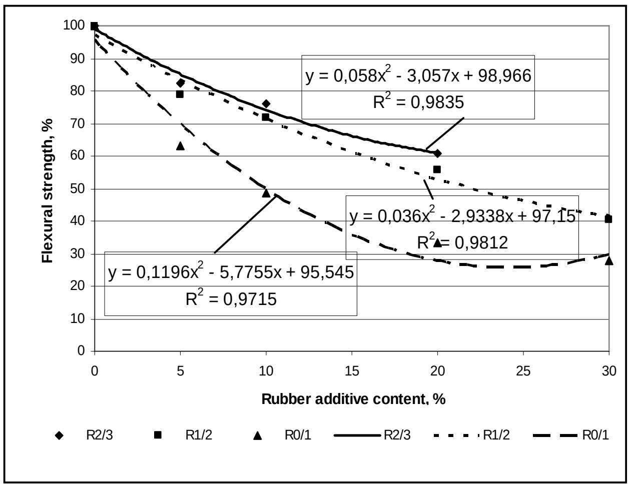

Fig. 6. Flexural strength relationship for different fraction and amount rubber additives

The calculated correlation factor values confirm that flexural strength results of hardened concrete with R are reliable. From this point of view we can predict flexural strength of concrete with rubber waste additive by using mathematical regression equations in Fig. 6.

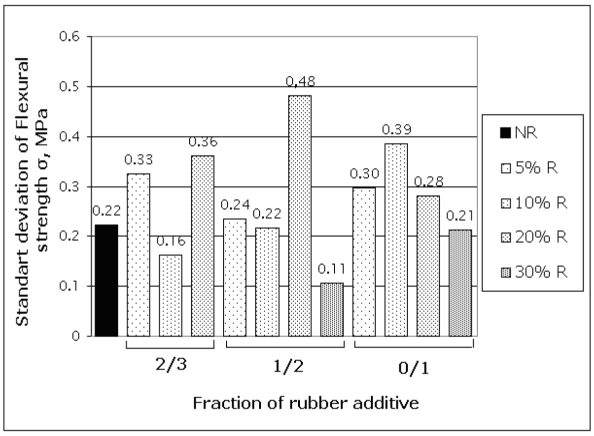

Fig. 7. Standard deviation of NR and R of flexural strength

In Fig. 7 standard deviation of flexural strength of NR and R are shown. It was obtained that standard deviation values vary between 0.11 MPa and 0.48 MPa. It was observed that 20 percent of R 1/2 fraction have highest scattering results of flexural strength, meanwhile specimens with 30 % of rubber waste additive (fr. 1/2) with the 0.11 MPa of standard deviation have lowest. From Fig. 7 we can figure that rubber waste additive amount or fraction do not effect the standard deviation of concrete flexural strength.

The results of compressive strength with different fractions and amount rubber waste aggregate and without RW are shown in Fig. 8. It was obtained that the size, proportions and surface texture of rubber articles noticeably affect compressive strength of concrete. The results presented that control specimen having initial compressive strength of average 64.3 MPa. However it was indicated that the concrete with 5 percent of rubber waste aggregate had compressive strength reducing from 64.3 MPa to 46.7 MPa, accordingly, with reducing RW fraction. In this study it was observed that increasing rubber waste amount to 10 percent from aggregate mass, compressive strength decreases from 46.9 MPa to 33.8 MPa using rubber waste from coarse (2/3) to fine (0/1) fraction respectfully. Interestingly, these initial strength values dropped to about 22.9, 22.2 and 14.2 MPa when 20 % of total aggregate volume was replaced for the concretes with the different fractions rubber. From Fig. 8 we can notice that comparing to none rubberized concrete highest compressive strength decrease is in specimens with 30 % by aggregate volume waste rubber particles. It can be seen that 30 % of rubber waste 1/2 fraction decreases 84 % and 0/1 fraction – 85 % concrete compressive strength.

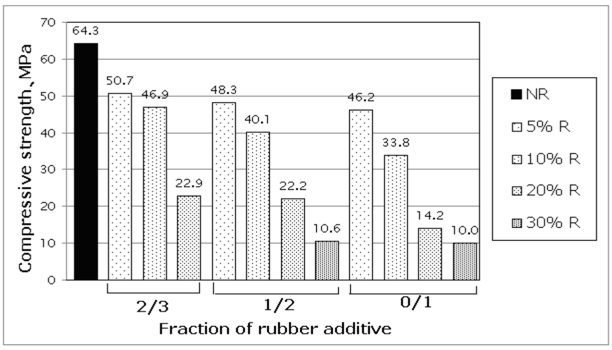

Fig. 8. Comparison of compressive strength of concrete with different fraction of rubber additive

In comparison with the control specimen, the addition of rubber waste reduces the compressive and flexural strengths of the specimen significantly. The reduction of compressive strength in rubber particles may be attributed of two reasons: first, because the rubber particles are more soft (elasticity deformable) than the surrounding cement paste, on loading, cracks are initiated quickly around the rubber particles in the mix, witch accelerates the failure of the rubber – cement matrix; secondly, due to the lower strength of the crumbed rubber particles comparing to the strength of concrete aggregates [28, 29].

Fig. 9 shows the compressive strength relationship of the different fraction and different amount tires rubber waste particles comparing to none rubberized specimens. The compressive strength reduction by increasing rubber waste particles has linear trend. Mathematical functions for calculating compressive strength for different fractions (fr. 2/3, 1/2, 0/1) of rubber waste are shown in Fig. 9. The obtained correlation factor value varies form 0.97 to 0.99 respectively to rubber waste fraction (by linear trend, correlation factor value varies from 0.91 to 0.97). Calculated the correlation factor values confirm that compressive strength results of hardened concrete are reliable. Using mathematical functions shown in Fig. 9 we can predict the compressive strength of R.

In this research also the ratio of the flexural strength and compressive strength of R to that of NR was calculated. It was determined that using 30 % tires rubber waste additive in concrete, compressive strength reduces more than 6 times comparing to control specimen, while flexural strength – maximum 3.6 times (30 % of R fr. 0/1). Lower decrease of the flexural strength for R may be attributed by higher influence of adhesion of cement paste to aggregates or rubber particles. Because of the great roughness surface of rubber particles the hardened cement paste has better adhesion to rubber particles than sand. From this reason concrete with rubber particles have less reduction of concrete flexural strength.

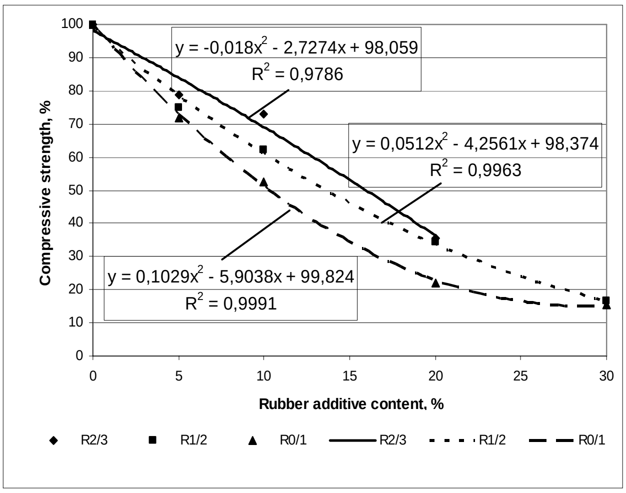

Fig. 9. Compressive strength relationship for different fraction and amount rubber additives

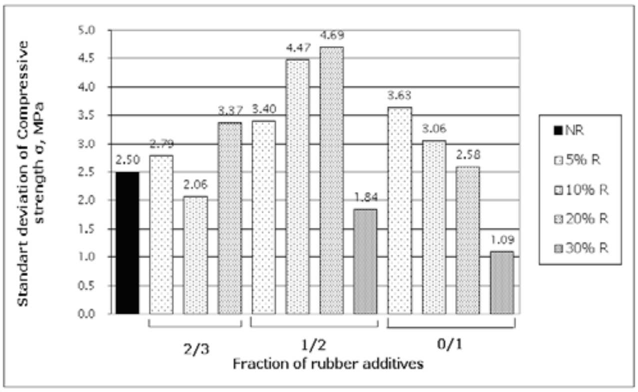

Fig. 10. Standard deviation of NR and R of compressive strength

In Fig. 10 standard deviation of compressive strength of NR and R are shown. From this figure we can see that standard deviation varies from 1.2 MPa of using R fraction 0/1 of 30 percent amount by aggregate volume to 4.7 MPa of using RC fr. 1/2 of 20 % accordingly. From this point of view we can confirm that rubber waste additive do not effect the standard deviation of concrete compressive strength.

The similar variations of concrete strength properties with rubber waste additive were studied by other authors [6, 8, 27, 29, 30]. They observed that concrete strength decreased considerably when amount of rubber aggregates increases. Topçu et al. [6] estimated that different amount of rubber waste (from 20 % to 50 % of aggregate mass) decreased flexural strength from 13.5 % to 51 %, while commpresive strength decreases from 30 % to 73 %. Naik et al [8] indicated that the compressive strength get reduction of about 65 % in compressive strength when fine aggregate was fully replaced by fine crumb rubber. Güneyisi et al. [29] was observed that there was about 85 % reduction in the compressive strength when 50 % of the total aggregate volume was replaced by rubber, irrespective of the silica fume content. Benazzouk et al. [30] indicated that compressive strength in self compacting concrete decreased 40 % when 14 % of rubber waste amount in concrete was added.

4. CONCLUSIONS

1. The addition of rubber waste additive (20 % of aggregate mass) to concrete decreased the dynamic modulus of elasticity about 50 %. The amount of rubber waste had more noticeable effect on dynamic modulus of elasticity than the particles size of rubber waste.
2. The addition of rubber waste additive (20 % of aggregate mass) decreased the quality factor about 20 % but increase damping decrement of concrete about 37.5 %. The amount of rubber waste had more noticeable effect than the used fraction of rubber waste additive.
3. The concrete with rubber waste additive more damp structure-borne noise than concrete without additive, although have worsen concrete strength properties.
4. The addition of rubber waste decrease the compressive strength and flexural strength by polynomial trend with increasing tires rubber waste additive.
5. The finest fraction (0/1) of rubber waste additive has more significant effect of decreasing flexural strengths than coarse fraction of rubber waste additive, but has no significant effect onto compressive strength.
6. Concrete with rubber waste can be used for isolation of structure-borne-noise in buildings, foundations and industrial floors.

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