ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 13, No. 4. 2007

Acoustical Characteristics and Physical-Mechanical Properties of Plaster with Rubber Waste Additives

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

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

Received 03 September 2007; accepted 09 October 2007

Additives from the recycled tires were tested in the new sound absorption material. The aim of this research was to investigate the acoustical characteristics and physical-mechanical properties of plaster with rubber waste additive. Two different mixtures were investigated: one without rubber waste additive, another with 0/1 fraction rubber waste additive. The rubber waste additive was used in mixture replacing 30 % of fine aggregate. The influence of rubber waste additive on plaster acoustical characteristics and physical-mechanical properties was evaluated.
Keywords: Rubber waste additive, acoustical characteristics, physical-mechanical properties.

1. INTRODUCTION

The undesirable and potentially hazardous noise in surrounding environment has become very crucial and complex problem of late years. Especially this problem is relevant in residential area of towns. To solve this problem various methods are used. One of methods to reduce the noise level in residential buildings and their environment is to use sound absorption materials. Various materials (e. g. foam of fibreglass) are used for the sound absorption. These materials have usually some practice limitations: as they are enough expensive; they have low structural strength; they are thick in thickness. Therefore the new materials which have attractive characteristics: are low-cost, thin in thickness and simple to produce them are under investigation of late years [1 – 6].

On the other hand during the last years we are up against ecological problem of utilization of tires. Many waste tires are currently stockpiled in many countries around the world, for example each year about 180 million rubber tyres cumulate only in European Union [7]. These stockpiles are dangerous because they pose a potential environmental concern, fire hazards, and provide breeding grounds for mosquitoes [8, 9].

Innovative solutions to meet the challenge of tire disposal problem have long been in development and the promising options are: reuse of ground tire rubber in number of plastic and rubber products, thermal incineration of waste tires for production of heat and electricity, use as fuel for cement kiln, as feedstock for making carbon black, use as reefs in marine environment and use of tire rubber in asphalt pavement and Portland cement plaster mixtures and al. [10 – 13].

One of range there recycled tires can be used is creating new sound absorption materials as plaster with rubber waste additive. Plaster can be made cheaper by replacing its fine aggregate (sand) with granulated rubber crumbs from used rubber tires. These granulated rubber crumps are made through a process called continuous shredding [14].

The aim of this research was to investigate the influence of recycled rubber waste additive on acoustical characteristics and physical-mechanical properties of plaster. Sound absorption characteristics of the plaster were evaluated by a sound absorption coefficient. Physical-mechanical properties were determined by static and dynamic modulus of elasticity, compressive and flexural strengths and porosity of plaster – by water absorption kinetics.

2. EXPERIMENTAL

2.1. Materials and specimens

In this research two different plaster mixtures were used: plaster without rubber waste additive, and plaster with 0/1 fraction rubber waste additive to determine the effect of crumbed rubber waste on plaster acoustical characteristics and physical – mechanical properties.

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

As a fine aggregate sand fractions 0/4 and 0/1 were used. In the mixtures plasticizing admixture 1.2 % from the cement content was used. Mechanically crumbed rubber waste from the used tires was used in one of the mixtures. Part of the fine aggregate of this mixture was replaced by a rubber waste additive from the used tires (30 % from fine aggregate by mass). The plasticizing admixture based on policarboxile polymers was used with density of solution 1040 kg/m^3. Rubber waste was classificated to fraction 0/1 (from JSC "Metaloidas" Šiauliai, Lithuania) with density of 950 kg/m^3 – 1050 kg/m^3.

To examine the influence of crumbed rubber waste additive on the characteristics of plaster mixture and hardened plaster two plaster mixtures were proportioned and mixed under laboratory conditions: none rubberized plaster (NRP) and rubberized plaster (RP). To determine acoustical characteristics and physical-mechanical properties

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

Table 1. Proportions of plaster mixtures

Rubber waste fraction	Materials content for 1m^3 of plaster mixture					
	Rubber waste, kg	Cement, kg	Sand 0/1, kg	Sand 0/4, kg	Superplastycizer, kg	Water, l
0/1	159	423	310	724	5.08	220
–	–	423	443	1034	5.08	220

two different type specimens of both mixtures were made: (1000 × 1000 × 30) mm (on gyps board slabs) specimens for determination of acoustical characteristics of plaster and (100 × 100 × 100) mm (prisms) and (160 × 40 × 40) mm (cubes) specimens for determination of physical-mechanical properties of plaster. Proportions of the plaster mixtures are presented in Table 1.

2.2. Test methods

Plaster specimens – slabs ((1000×1000×30) mm) were cured in natural conditions, while prisms ((160 × 40 × 40) mm) and cubes ((100 × 100 × 100) mm) were cured in conditions according EN 12390-2 and tested after 28 days.

Sound absorption of plaster specimens were measured by the reverberation – room method at 1/3 octave intervals in the frequency range 100 Hz – 5000 Hz based on ISO 354.

The slump, density and air entrainment of plaster mixture were determined by LST L 1346, 12350-6 and 12350-7. Density of the plaster was determined by EN 12390-7, compressive strength – by EN 12390-3. Static modulus of elasticity was determinate according ISO 6784. Dynamic modulus of elasticity was determined according to the resonant frequency of vibration enhancing the flexural stress. Porosity of the plaster was determined by water absorption kinetics by GOST 12730.4

Sound absorption of materials is usually is characterized by sound absorption coefficient (α). In this research the random incidence sound absorption coefficient was determined:

$$\alpha = \frac{A_2 - A_1}{S}, \quad (1)$$

where: S is the area of specimen, m^2; A_2 is the equivalent absorption area of specimen, m^2; A_1 is the equivalent absorption area of reverberation chamber, m^2:

$$A_2 = \frac{55.3V}{cT_2}, \quad (2)$$

$$A_1 = \frac{55.3V}{cT_1}, \quad (3)$$

where: V is the volume of reverberation chamber, m^3; T_2 and T_1 is the accordingly reverberation time in reverberation chamber with specimen and without specimen; c is the sound speed in air.

3. RESULTS AND DISCUSSION

3.1. Characteristics of mixture

Properties of the fresh mixture (slump and air entrainment) are presented in Table 2.

Table 2. Properties of the fresh plaster

Plaster mixture properties	Slump, cm	Air entrainment, %
0 % rubber	6.5	9.0
	6.4	7.5
	7.5	7.6
	6.8	8.0
30 % rubber	4.9	20.0
	4.8	22.0
	5.6	25.0
	5.1	22.3

As shown in Table 2 the slump of NRP varies from 6.5 cm to 7.5 cm while slump of RP mediate from 7.5 cm to 9.0 cm. The reduction of workability in RP can be explained by more complicated surface texture and large specific surface of rubber waste particles than that of the control mixture with fine sand aggregates (0/1 fraction and 0/4 fraction). The results of air-entrainment measurements of NRP and RP are displayed in Table 2. The table clearly indicates that the addition of rubber particles in the cement matrix increases the level of air-entrainment. The values range between about 4.8 % – 5.6 % and 20.0 % – 25.0 %, respectively, for NRP and RP specimens with a 30 % rubber volume ratio. The higher air content in mixtures may be due to the capability of rubber particles to entrap air at their rough surface due to their non-polar nature. Similar observations were also made by several authors [11, 15, 16].

3.2. Acoustical characteristics

To examine the influence of rubber waste additive on sound absorption of plaster, four slabs ((1000 × 1000 × 30) mm) were installed on a floor of a special acoustical chamber. The total area of specimens was 4 m^2.

According to standard (ISO 354) reverberation time of empty chamber was measured. Secondly reverberation time with specimens accordingly NRP and RP was measured.

Fig. 1 shows the reverberation time of empty chamber and chamber with the specimens.

From Fig. 1 we can see that the reverberation time car-0rying into chamber specimen has decreased significantly (from 0.261 s to 0.425 s) in middle range between 400 Hz and 1600 Hz. In low frequency range between 100 Hz and 400 Hz and high frequency range 1600 Hz and 5000 Hz it has decreased insignificantly (from 0.014 s to 0.262 s). And finally the reverberation time of chamber differ insignificantly (from 0.016 s to 0.227 s) between both specimens (with RP and with NRP).

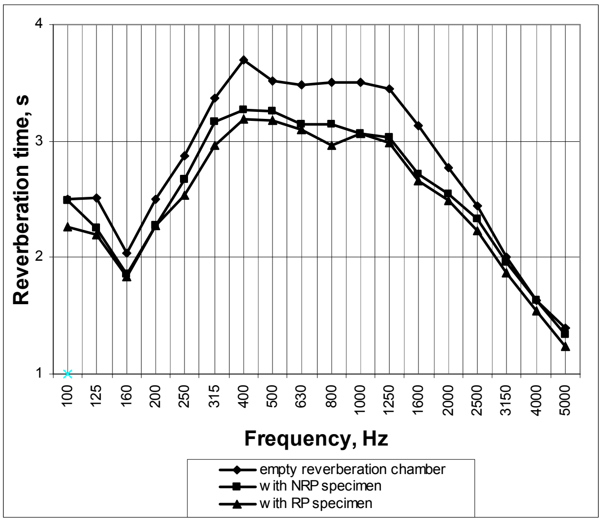

Fig. 1. Reverberation times of the chamber without and with specimens

Fig. 2 shows the equivalent absorption area of specimen with rubber additive and without rubber additive.

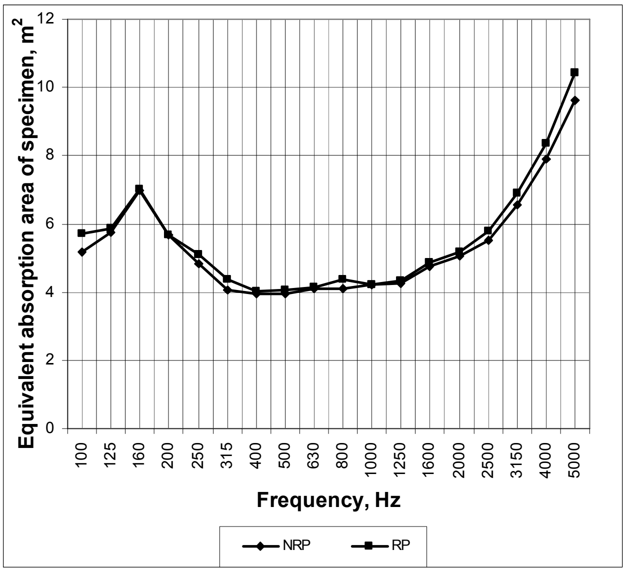

Fig. 2. Equivalent sound absorption area of NRP and RP plasters

From Fig. 2 we can see what equivalent absorption area of RP specimen has increased insignificantly (from 0.1 m^2 to 0.78 m^2) in comparison with RP specimen. It shows that rubber additive and porosity has insignificant influence on equivalent sound absorption area of the specimen.

Fig. 3 shows sound absorption of RP specimen and NRP specimen.

From Fig. 3 we can see that the value of plaster sound absorption coefficient is low. Additions of rubber have changed the sound absorption coefficient insignificantly in whole frequency range (av. 0.05) in spite of fact that RP specimen has higher porosity, less density (see chapter 3.3.) This may be explained that sound energy loss is small in RP specimen structure. At some frequencies 2500 Hz – 5000 Hz sound absorption had changed significantly (from

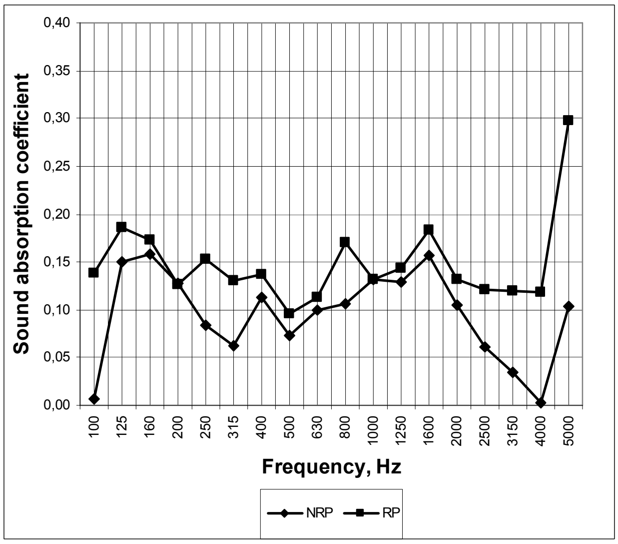

Fig. 3. Sound absorption coefficient of NRP and RP plasters

0.084 to 0.194). It can be caused by resonance effect in RP specimen structure.

3.3. Physical-mechanical properties

Table 3 shows the test results of dry unit weight, compressive strength and flexural strength of plaster modified by styrene butadiene rubber and control plaster. This table clearly indicates that the addition of rubber particles reduces the dry unit weight, compressive strength and flexural strength of plaster.

Table 3. Properties of hardened plaster

Plaster properties	Dry unit weight, kg/m^3	Compressive strength, MPa	Bending strength, MPa
0 % rubber	2115	39.5	
	2124	37.9	5.90
	2127	37.8	6.48
	2152	38.5	6.70
	2122	37.9	6.36
30 % rubber	1405	4.5	
	1405	4.8	2.65
	1403	5.2	2.33
	1414	5.7	2.71
	1404	5.1	2.56

The reduction of dry unit weight in RP can be explained by lower density of rubber waste particles (1020 kg/m^3) compared with fine aggregate – sand particles density (2650 kg/m^3).

The reduction of compressive strength in RP may be attributed to 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, wich accelerates the failure of the rubber – cement matrix; secondly, due to the lower compressive strength of the crumbed rubber particles comparing to the strength of plaster aggregates [12, 18 – 23].

Figure 4 shows the load – deflection curve of the RP and NRP prisms. As expected, the flexural strength decreases with the inserting of rubber waste additive. It changes from average 6.36 MPa (2.85 kN) for control plaster to 2.56 MPa (1.11 kN) for plaster containing 30 % rubber waste additive.

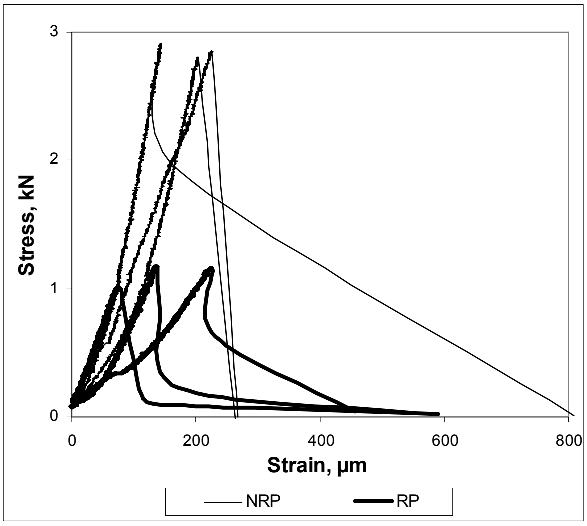

Fig. 4. Stress-strain relationship of flexural strength of plaster

In this research also the ratio of the compressive strength and flexural strength of RP to that of NRP was calculated. It was determined that using 30 % tires rubber waste additive in plaster, compressive strength reduces 7 times comparing to control plaster, while flexural strength – only 2.5 times. Lower decrease of the flexural strength for RP may be attributed to later formation of cracks in cement matrix.

Results in the form of static and dynamic modulus of elasticity of NRP an RP specimens are given in Fig. 5.

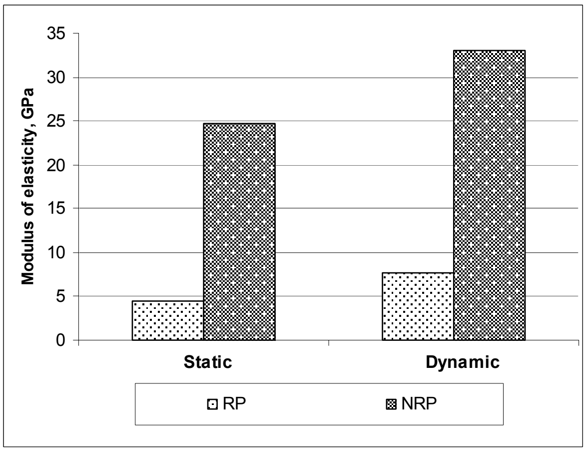

Fig. 5. Modulus of elasticity of plaster

Fig. 5 shows that both static and dynamic moduli of elasticity decrease from approximately 24.76 GPa to 4.45 GPa and 32.94 GPa to 7.68 GPa respectively for the plaster with rubber waste additive. It means that as static as dynamic modulus of elasticity decreases by 4 – 5 times of RP. The decrease of both modulus of elasticity can be explained by higher air entrainment of fresh RP (see Table 2) and low modulus of elasticity of small rubber particles, which is much lower as replaced fine aggregate (sand 0/1 fraction and sand 0/4 fraction) modulus of elasticity.

In this research the stress-strain relationship of the RP and NRP (Fig. 6 and Fig. 7) under static compressive load was estimated.

From Fig. 6 and 7 we can see that the NRP deformation on *fc*/3 compressive load after 3 cycles varies from 58.5 μm to 63.4 μm while RP – from 87.3 μm and 103.5 μm. The results indicate that deformations increased respectively by 33 % – 39 % in plaster with elastic additive from tires rubber waste. Also we can see in Fig. 7 that strain deformations under the stress varies from –12 μm to 4 μm. The negative set deformations for RP specimens can be explained by high elasticity of tires rubber waste additive, which gives elongation of the specimens.

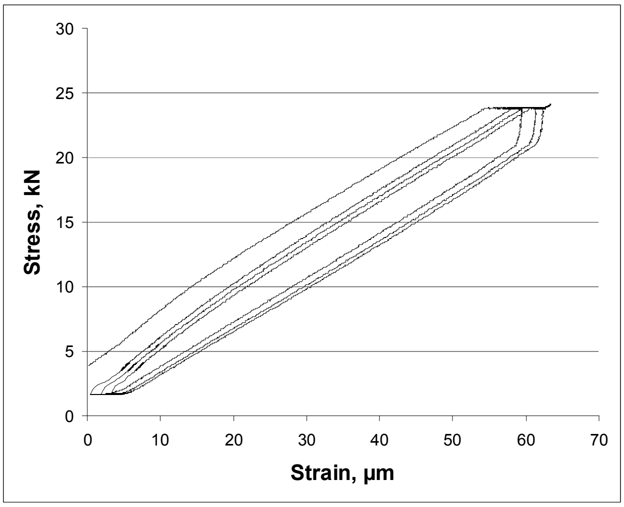

Fig. 6. Stress-strain relationship for NRP

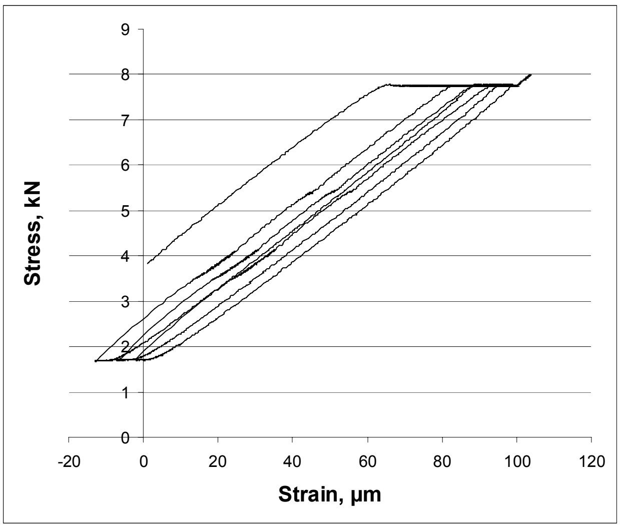

Fig. 7. Stress-strain relationship for RP

Porosity parameters of plaster with and without rubber waste particles 0/1 fraction are presented in Fig. 8.

It was obtained (Fig. 8) that porosity parameters change in RP comparing to control plaster. The increasing of total porosity for RP was observed in this study, while using tires rubber waste additive open (capillary) porosity reduces. The insignificant influence on the RP equivalent sound absorption area and sound absorption coefficient comparing to NRP (Figs. 1 – 3) can be explained by decreasing of capillary porosity of RP, because open porosity has big influence on sound absorption. As in previous studies was estimated [17], the close porosity is much higher than that of plaster without any rubber additives due to larger amount of air contained in such kind of plaster mixtures and close pores contained in rubber particles themselves.

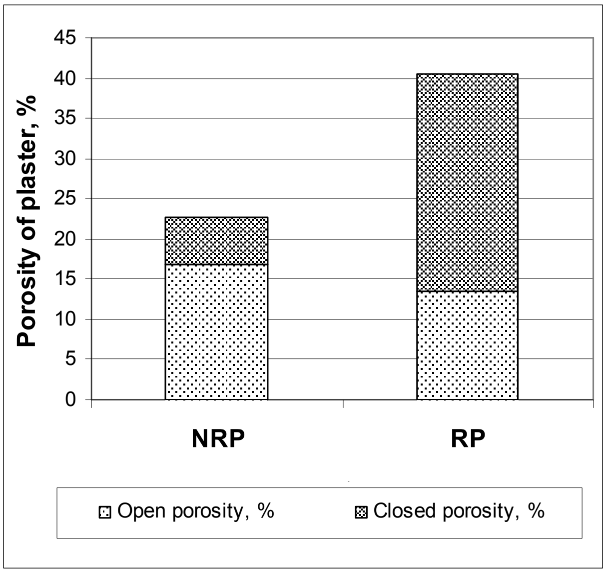

Fig. 8. Porosity parameters of plaster

Plaster freezing and thawing resistance can be predicted using the Sheikin [24] criterion K_F. According to this criterion a concrete is considered to be frost resistant when the volume of closed pores exceeds the increase volume of water in plaster capillary pores during the water freezing.

$$K_F = \frac{P_u}{0.09 P_a}, \quad (4)$$

where: P_u is the closed porosity of concrete (air pores), %; P_a is the open porosity of concrete (capillary pores), %.

After calculation of criterion K_F according to closed and open porosity of plaster, it was obtained that plaster with fine rubber waste additives (fraction 0/1 mm) the value of this criterion is about 7 – 8 times higher than that of plaster without rubber additives, which increase plaster freezing and thawing resistance.

4. CONCLUSIONS

1. Rubber addition has decreased slump and increased air entrainment of RP mixture as compared with NRP mixture.
2. The rubber waste additive has insignificant influence on plaster equivalent sound absorption area and sound absorption coefficient.
3. Rubber addition has reduced the dray unit weight, compressive and flexural strength of RP as compared with NRP.The static and dynamic modulus has decreased of RP compared with NRP.
4. The plaster with rubber additive has bigger deformation, RP specimen deformations are 33 % – 39 % bigger than NRP specimen.
5. The changes of porosity (increasing of closed porosity) and aggregates static modulus of elasticity has insignificant influence on the sound absorption coefficient of plaster with rubber additives.
6. The plaster with rubber waste additive has better resistance of freezing – thawing and durability because of larger closed porosity.
7. Although plaster with rubber additives has good physical-mechanical properties it has bad acoustical characteristics (low sound absorption coefficient) and it isn't suitable to use as acoustical plaster.

REFERENCES

1. **Vašina, M., Hunhes, D. C., Horoshenkov, K. V., Lapcik Jr., L.** The Acoustical Properties of Consolidated Expanded Clay Granulates *Applied Acoustics* 67 2006: pp. 787 – 796.
2. **Zhou Hong, Li Bo, Huang Guangsu.** Sound Absorption Behaviour of Multiporous Hollow Polymer Micro-spheres. *Materials Letters 60* (2006) 3451-3456.
3. **Zhou Hong, Li Bo, Huang Guangsu, He Jia.** A Novel Composite Sound Absorber with Recycled Rubber Particles *Journal of Sound and Vibration* 304 2007: pp. 400 – 406.
4. **Seung Bum Park, Dae Seuk Seo, Jun Lee.** Studies on the Sound Absorption Characteristics of Porous Plaster Based on the Content of Recycled Aggregate and Target Void Ratio *Cement and Concrete Research* 35 2005: pp. 1846 – 1854.
5. **Laukaitis, A., Fiks, B.** Acoustical Properties of Aerated Autoclaved Concrete *Applied Acoustics* 67 2006: pp. 284 – 296.
6. **Zhou, H., Huang, G. S., Chen, X. R., He, X. R.** Advances in Sound Absorption Polymers *Progress in Chemistry* 16 2004: pp. 450 – 455.
7. **Silvestravičiūtė, I., Šleinotaitė-Budrienė, L.** Possibility to Use Scrap Tires as an Alternative Fuel in Cement Industry *Environmental Research, Engineering and Management* 3 (21) 2002: pp. 38 – 48 (in Lithuanian).
8. **Nehdi, M, Khan, A.** Cementitious Composites Containing Recycled Tire Rubber: an Overview of Engineering Properties and Potential Applications *Cement Concrete Aggregate ASTM* 23 (1) 2001: pp. 3 – 10.
9. **Nabil M. Al-Akhras, Mohammed M. Smadi.** Properties of Tires Rubber Ash Plaster *Cement Concrete Composites* 26 2004: pp. 821 – 826.
10. **Tarun, R. N., Siddique, R.** Properties of Plaster Containing Scrap Tire Rubber – an Overview *Report No. CBU-2002-06 REP-459* 2002.
11. **Benazzouk, A., Douzane, O., Mezerb, K., Queneudec, M.** Physico-Mechanical Properties of Aerated Cement Composites Containing Shredded Rubber Waste *Cement Concrete Composites* 28 2006: pp. 650 – 657.
12. **Eldin, N. N., Senouci, A. B.** Rubber Tire Particles as Plaster Aggregate *Journal of Material Civil Engineering ASCE* 5 (4) 1993: pp. 478 – 496.
13. **Fatuhi, N, Clark, N.** Cement-Based Materials Containing Tire Rubber *Construction Building Materials* 10 (4) 1996: pp. 229 – 236.

14. **Skripkiūnas, G., Grinys, A.** Using Tires Rubber Waste for Modification of Plaster Properties *Building and Architecture. Proceedings of Conference* Kaunas, "Technologija" ISBN 9955-09-851-1 2005: pp. 132 – 137 (in Lithuanian).
15. **Topçu, I. B.** The Properties of Rubberized Plaster *Cement and Concrete Research* 25 (2) 1995: pp. 304 – 310.
16. **Toutanji, A. H.** The Use of Rubber Tire Particles in Plaster to Replace Mineral Aggregates *Cement Concrete Composites* 18 1996: pp. 135 – 139.
17. **Skripkiūnas G., Grinys A., Daukšys M.** Using Tires Rubber Waste for Modification of Plaster Properties *Sustainable Construction Materials and Technologies International Conference* Coventry 11 – 13 June 2007 ISBN 987-0-415-44689-1
18. **Skripkiūnas, G., Grinys, A., Černius, B.** Deformation Properties of Plaster with Rubber Waste Additives *Journal of Materials Science* 13 (3) 2007: pp. 219 – 223.
19. **Papakonstantinou, C. G., Tobolski, M. J.** Use of Waste Tire Steel Beads in Portland Cement Concrete *Cement and Concrete Research* 36 (9) 2006: pp. 1686 – 1691.
20. **Khatip, Z. K., Bayomy, F. M.** Rubberized Portland Cement Concrete *Journal of Material Civil Engineering ASCE* 11 (3) 1999: pp. 206 – 213.
21. **Topçu, I. B., Avcular, N.** Collision Behaviors of Rubberized Concrete *Cement and Concrete Research* 27 (12) 1997: pp. 1893 – 1898.
22. **Lee, B. I., Burnett, L., Miller, T., Postage, B., Cuneo, J.** Tyre Rubber Cement Matrix Composites *Journal of Material Science Letter* 12 (13 1993: pp. 967 – 968.
23. **Güneyisi, E., Gesoğlu, M., Özturan, T.** Properties of Rubberized Concretes Containing Silica Fume *Cement and Concrete Research* 34 2004: pp. 2309 – 2317.
24. **Sheikin, A. E., Schekovskyj, J. V., Bruser, M. I.** Properties and Composition Cement Based Concrete. Moscow: Stroiizdat, 1979: 344 p. (in Russian).

Presented at the National Conference "Materials Engineering'2007"
(*Kaunas, Lithuania, November 16, 2007*)