LABORATORY TESTS OF WASTE MIXTURES CONSISTING RECYCLED TYRE RUBBER AND COAL-MINING WASTES

Adrian CIOŁCZYK [1], *Konrad WALOTEK* [2]

[1] Department of Geotechnics and Roads, Faculty of Civil Engineering, The Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland
[2] Department of Geotechnics and Roads, Faculty of Civil Engineering, The Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland

Adrian.ciolczyk@polsl.pl, konradwalotek@gmail.com

DOI: 10.35181/tces-2019-0008

Abstract. *The paper presents the results of research on the application of recycled tyre rubber, in the form of rubber dust, in mixtures bound with a hydraulic binder, to improve the physical and mechanical parameters of unburnt coal-mining slates. In particular, the parameters related to resistance to water and susceptibility of bound mixtures. The research was carried out on mixtures containing unburnt coal-mining slate, rubber dust, fly ash and cement, as well as on reference mixtures with no rubber dust in their composition. The observations were aimed at checking how the varied content of rubber dust affects the physical and mechanical parameters of the samples.*

Keywords

Cyclic Load Test, Fly Ash, Recycled Tyre Rubber, Rubber Dust, Secondary Raw Materials, Unburned Coal-mining Slate, Waste Materials.

1. Introduction

In the era of continuous development of industry, the demand for the development of transport infrastructure is constantly growing. This is associated with a constant increase in demand for natural soils or natural aggregates, meeting the requirements in terms of physical and mechanical parameters, set in the transport construction industry. It should be remembered, however, that due to continuous exploitation, the amount of such natural resources is constantly decreasing. Therefore, it is a good solution to search for technologies allowing to obtain the required physical and mechanical parameters, using as much waste materials as possible, which are often a side effect of human activity. Unburnt coal-mining slate is a coal vein accompanying rock obtained as a by-product of hard coal mining in the Silesian agglomeration. It is an aggregate used in a number of applications in the transport construction industry. However, due to low physical and mechanical parameters and high sensitivity to water, it is mainly used for layers or structures with lower responsibility. In such cases, the material used is not required to be frost resistant and of high strength. Therefore, it is still not possible to make full use of the obtained waste material [1], [2], [3].

Rubber granulate is a secondary raw material obtained as a result of mechanical shredding or cryo-shredding of used car tyres. Since the 1970s, this material has been successfully used to improve the physical and mechanical parameters of mineral-asphalt mixtures, using "wet" and "dry" methods, as well as to improve the properties of the bituminous binder itself in modified asphalts. In recent years, sports surfaces [2], [4], [5] have become an additional source of demand for rubber granulates. As in the case of unburnt coal-mining slate, the known and used methods of rubber granulate utilization are not able to fully utilize the continuous production of rubber waste.

The paper presents the results of tests of hydraulically bound samples consisting of unburnt coal-mining slate, rubber dust, fly ash [6] and cement, as well as control samples in the composition of which no rubber dust was used. The aim of the study was to check how the varied content of rubber dust affects the physical and mechanical parameters of the analysed mixtures. Positive results of the study would allow to increase the number of applications of two materials, which can be treated as waste, in transport construction that is characterized by a very high consumption of granular materials.

2. Mixture of slate – rubber – ash - cement

Unburnt coal-mining slate is characterized by low values of physical and mechanical parameters and high sensitivity to water. This sensitivity is manifested by degradation of aggregate grain size when exposed to water (Fig. 1).

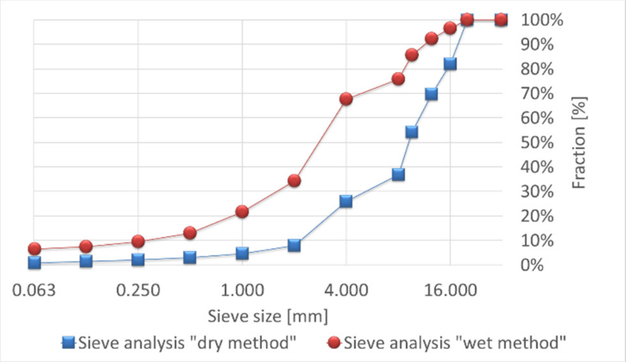

Fig. 1: Influence of exposure to water on the change in aggregate grain size.

This degradation causes the decomposition of aggregate grains into smaller grains, which in effect reduces the load-bearing capacity of such material and as a result of the formation of clay fractions it can lead to the formation of frost heaves.

In order to protect the aggregate grains from the influence of water, the use of rubber dust has been proposed. This material, thanks to its properties allowing for concentrating the surface tension of water, should allow to reduce the intensity of aggregate exposure to water. Additionally, the use of rubber dust is supposed to reduce the effect of crushing the aggregate during its compaction and, due to its low weight, allows to obtain a mixture with a lower bulk density than standard mixtures bound with a binder.

The use of rubber dust alone, however, does not allow the expected results to be achieved immediately. This is because in order to take full advantage of the properties of rubber dust, it is necessary to achieve the maximum tight and closed structure of the sample, so that there are not too large free spaces in it. The free space accumulates water in its volume, which has a negative impact on aggregate grains, leading to their decomposition. In order to eliminate the problem of free space in the mixture, the addition of fly ash was used as a granulating material.

The last component of the mixes is cement. Due to its versatility, CEM I 32.5 R cement was used in this case. The addition of a binder is to guarantee an appropriate level of strength parameters and allow to create, together with ash and rubber dust, a matrix protecting the aggregate grain against harmful external influences.

3. Research Program and Preparation of Laboratory Samples

3.1. Research Program

The aim of the research program was to check how the varied content of rubber dust influences the change of strength and deformations parameters and parameters describing the cooperation of the material with water. The research program includes the following tests, each on a group of 3 samples:

- Compressive strength R7
- Compressive strength R28
- Absorbability test
- Capillary action test
- Cyclical load test (this test was made only on samples which recipe consists rubber dust)

Compressive strength tests after 7 and 28 days of maturation were performed according to the methodology contained in the PN-S-06103:1997 standard [7]. Absorbability was tested using the methodology according to PN-B-06250:1988 [8], while capillary actions test and cyclical load test were made according to the own method.

3.2. Preparation of Laboratory Samples

The procedure of preparation of laboratory samples included preparation of mixtures according to Table 1 from unburnt coal-mining slate with grain size 0/16 mm, rubber dust with grain size 0/2 mm, fly ash and CEM I 32.5 R cement. The samples were compacted (by 15 impacts per layer, in 2 layers) at optimal moisture content, determined according to PN-EN 13286-2:2007 [9] standard (as per Fig. 2), in cylindrical moulds 80 mm x 80 mm.

Tab. 1: Composition of prepared recipes depend on unburnt coal-mining slate dry weight

Recipe	Cement content [%]	Ash content [%]	Rubber dust content [%]
G0	5	5	0
G5	5	5	5
G10	5	5	10
G15	5	5	15

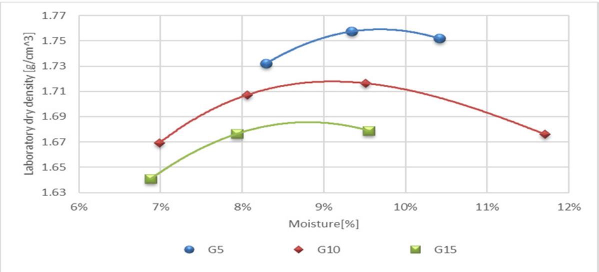

Fig. 2: Optimal moisture content in accordance to the II Proctor method.

As can be seen in the above graph, increasing the addition of rubber dust influences the reduction of the optimum moisture content. The optimum moisture content is 9.6% for the G5 mixture, 9.1% for the G10 mixture and 8.6% for the G15 mixture.

4. Laboratory Tests Results

4.1. Compressive Strength Test R7 and R28 [7]

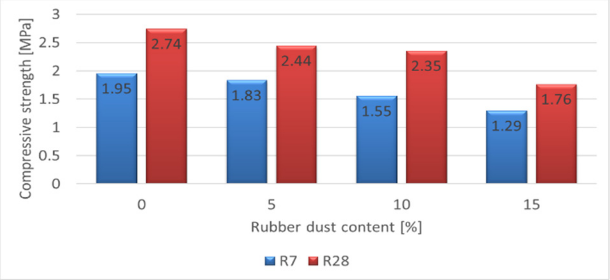

Fig. 3: Bar diagram of compression strength values R7 and R28.

The samples were subjected to compression strength tests (according to [7]). The results are illustrated in Figure 3. As can be seen, the addition of rubber dust reduces the compressive strength after 7 and 28 days of specimen care. In the case of G5 series samples after 28 days of care, the compressive strength equal to 2.44 MPa was obtained. Despite higher content of rubber dust, the G10 series samples manifest a slight decrease in compressive strength to 2.35 MPa, and the G15 series samples have the lowest compressive strength at the level of 1.76 MPa. The G0 control specimens achieved a compressive strength of 2.74 MPa.

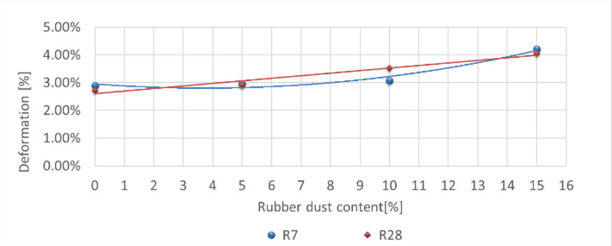

Fig. 4: Diagram of the ratio of the obtained deformations to the content of rubber dust.

During the compressive strength test, the final deformations of the specimen were also tested. The results of the test are presented in Figure 4. After a 7-day care period, the relationship between the deformation and the content of rubber dust was non-linear. The increase in the value of deformations between 5% and 10% of the addition of rubber dust was small, the increase in the value of deformations was observed only at 15% of the addition of rubber dust. In the case of a 28-day care period, the relation between the deformations and the content of rubber dust becomes very close to a linear one.

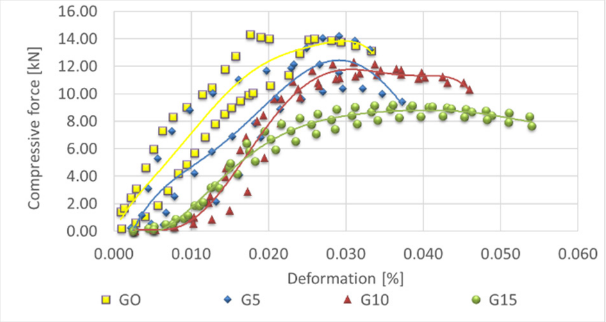

Fig. 5: Diagram of the increase in forces and stresses during compression of specimens.

Based on the results of the compressive strength test after 28 days of care, a graph of the relationship between the increase in deformation and the increase in compressive force was created. These data are illustrated in Figure 5. As it can be seen, the increasing content of rubber dust increases the specimen's deformability and causes a milder increase in compressive force. Additionally, it should be noted that the increasing addition of rubber dust reduces the dispersion between the obtained results. This may indicate its positive effect on the even distribution of stresses in the structure of the samples.

4.2. Absorbability Test [8]

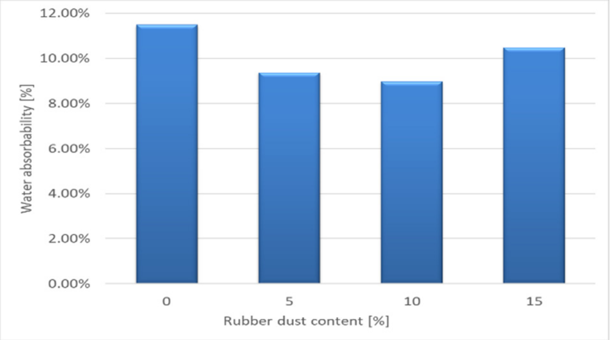

Fig. 6: Water absorbability diagram for each recipe.

The above graph shows the results of water absorbability of samples [8]. The best result, i.e. the lowest absorbability value, was obtained by samples made of G10 recipe (8.97%), the worst absorptivity value among the samples with a rubber composition was obtained by samples made of G15 recipe (10.48%). G5 samples have an absorbability of 9.36% and G0 control samples have an absorbability of 11.49%.

On the basis of the above results, it can be concluded that the content of rubber dust does not affect the absorbability values achieved in a linear manner. The extremum of the function of the dependence of absorbability to the share of rubber dust is around the addition of 10% of the dust, so it can be concluded that such a content of the dust additive oscillates around the value optimal for absorbability. In the case of G15 series samples, the increase in absorbability values is caused by too high a content of rubber dust. It causes excessive loosening of the structure of the whole sample and relaxation of rubber dust during sample ripening, leading to the formation of micro-cracks in the structure of the cement matrix.

4.3. Capillary Action Test

The samples were subjected to a test to determine the influence of rubber dust on the capillary action force of the samples. For this purpose, they were immersed in water to a depth of 2 cm from the base of the sample, and then for a period of 27 h, the height at which the water was pulled up was observed. Graph 7 shows the results of the test.

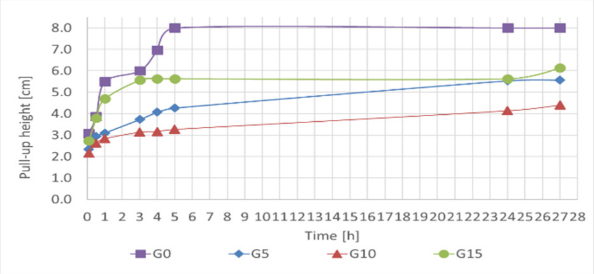

Fig. 7: Capillary water absorption height increase over time diagram.

As it can be seen, the best result, i.e. the lowest height of capillary action was obtained by samples from the G10 series (4.1 cm), the worst result was recorded for samples from the G15 series (6.4 cm). The G5 series samples reached a pull-up height of 5.2 cm and the G0 control samples reached the maximum pull-up height of the sample after just 10 hours of the test. None of the samples in which the composition was made of rubber reached the maximum height of capillary action, which in this case is the height of the sample equal to 8.0 cm.

Achieving a pull-up height equal to the height of the specimen could indicate the predisposition of the specimen to further increase the pull-up height of the water. The above results are identical to the results obtained for the water absorption test. The optimal value (giving the best results) oscillates around 10% of the addition of rubber dust (G10 series). In the case of the G15 series a deterioration of parameters in comparison to the other series of samples containing rubber dust can be observed again.

4.4. Cyclical Load Tests Results

Procedure of the test was adapted from repeated loading tests CBR [10], in this test the equipment used in compression tests was used instead of CBR shank. Tested samples were subjected to 20 compressing cycles in hydraulic press (fig. 8). Which cycle consists of loading the sample (with constant speed of 1.27 mm/min) to achieve deformation equal to 1.5 mm (ε = 1.9%) and unloading the samples to achieve compressive force equal 0.10 kN (0.02 MPa). The test was carried out to check how the varied content of rubber dust influences the range of the elastic deformations of the samples. Results of the test are presented in figures mentioned below (fig. 9 – 11). This figures presents measured compressive forces for demand deformations.

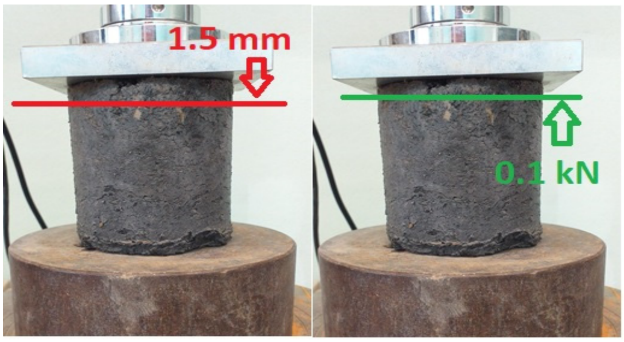

Fig. 8: Presentation of the cyclical load test step.

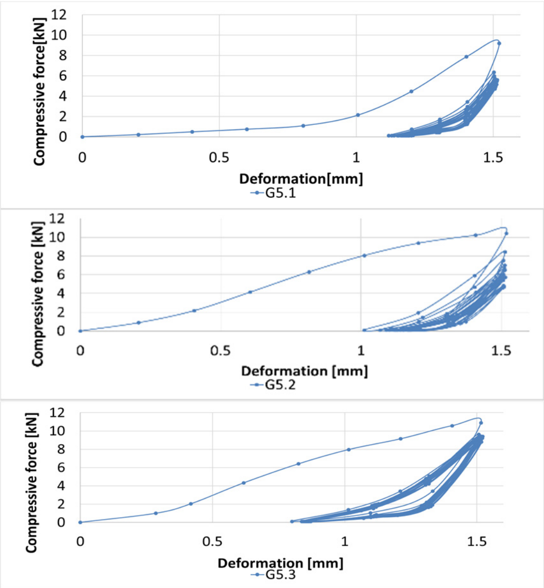

Fig. 9: Repeated loading test results as a function of cyclic force and penetration for a G5 series.

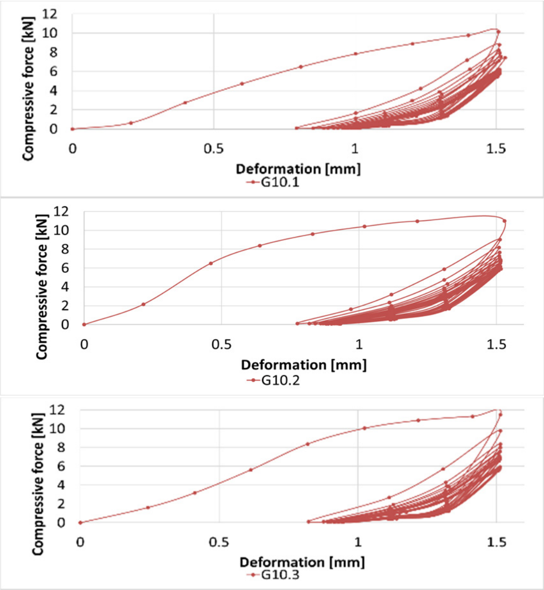

Fig. 10: Repeated loading test results as a function of cyclic force and penetration for a G10 series.

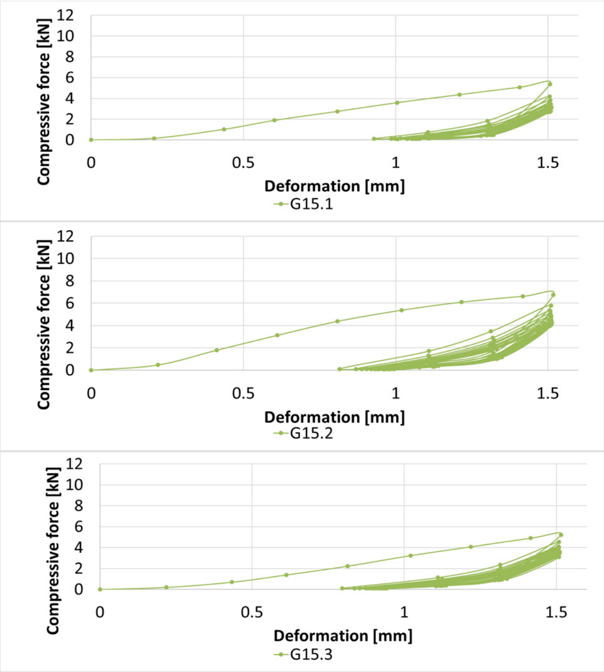

Fig. 11: Repeated loading test results as a function of cyclic force and penetration for a G15 series.

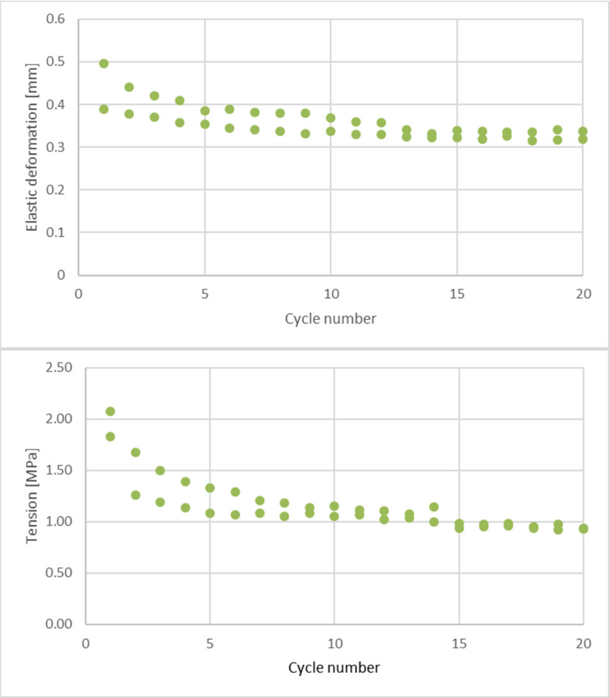

Fig. 12: Schedule of elastic displacements and stress in all test cycles for G5 series.

The G5 and G10 series specimens have the fastest increase in compressing force for the given displacements and achieve their highest values. For the G15 series, the compressing force rate for the given displacements, as well as the measured force values themselves, are the lowest. The G10 and G15 series samples are more repeatable than the G5 series. This may indicate a positive effect of rubber dust addition on homogenization of the internal structure of the samples. Higher content of rubber dust allows for more uniform compression of the specimen cross-section.

Diagrams 12-14 show the distribution of displacements in the elastic range and maximum stresses range obtained at a displacement of 1.5 mm. The results obtained for sample G5.3 were rejected from the data analysis, due to a large discrepancy between the values obtained and the other samples from this series. Comparative analysis was performed for the values of displacements and stresses obtained for 20 test cycles U20 and F20, respectively (Table 2). On the basis of the presented graphs it can be noticed that in each of the tested series the degradation of the obtained values of displacements and stresses is stabilized in the vicinity of the 10th test cycle.

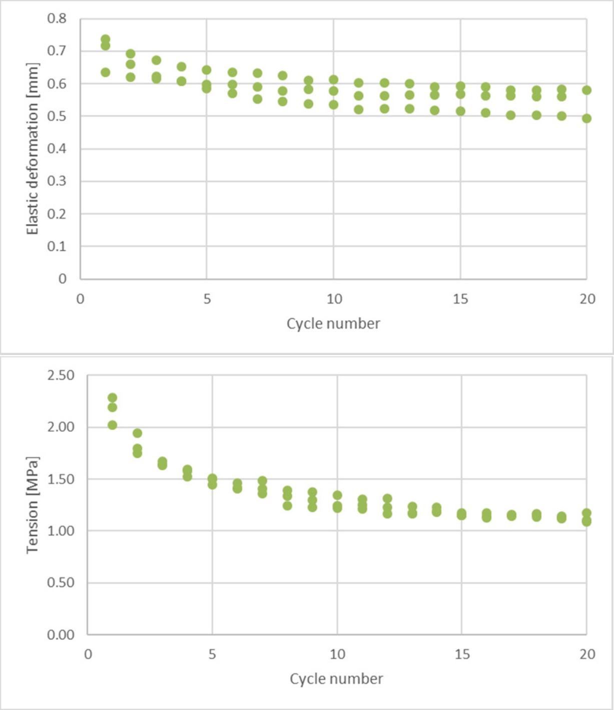

Fig. 13: Schedule of elastic displacements and stress in all test cycles for G10 series.

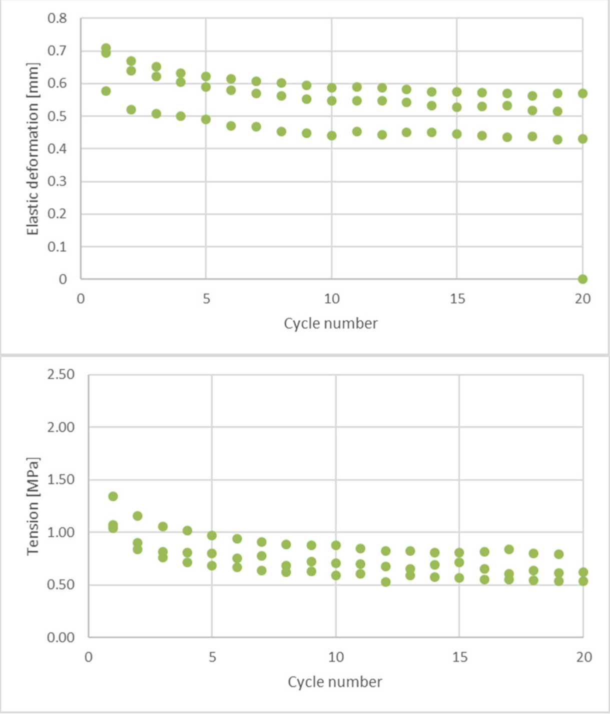

Fig. 14: Schedule of elastic displacements and stress in all test cycles for G15 series.

Tab. 2: Summary of mean U20 and F20 values

	G5	G10	G15
U_{20} [mm]	0.328	0.549	0.505
F_{20} [MPa]	0.935	1.12	0.677

Based on the above data it can be concluded that the increasing addition of rubber dust in the sample positively influences the increase in the range of elastic work of the tested material. In the case of specimens with 10% addition of rubber dust (G10 series) we observe the highest value of elastic displacements equal to 36.6% of total deformations performed on specimens. The lowest value of elastic displacements is obtained for specimens with 5% content of rubber dust, equal to 21.9% of total displacements. Despite the satisfactory percentage of stresses and displacements in the 20th test cycle, the G15 series specimens are characterized by low compressive strength. Therefore, in the case of mixtures with such a large amount of rubber dust, there may be a problem with meeting the requirements for road layers made of bonded mixtures [11].

5. Conclusions

After analysing the test results, it can be stated that the addition of rubber dust allows to obtain the range of elastic work at much greater displacements, in comparison to other materials related to the hydraulic binder. More precise recognition of the influence of other components on the behaviour of samples under cyclic loads could enable the development of mix formulas that would meet the requirements for bound mixtures according to WT-5 [11]. Increasing the range of elastic operation will allow to obtain higher fatigue life in cyclic load conditions. Improvement of the fatigue life efficiency of such mixtures could allow an increase in their applications in road construction and improve fatigue life of the whole road structure.

References

[1] WALOTEK, K. Analiza parametrów fizyko mechanicznych łupków przywęglowych nieprzepalonych ulepszanych spoiwami z dodatkami odpadów gumowych. Praca magisterska, Politechnika Śląska, Gliwice, 2017.

[2] IBDIM: Ocena i badania wybranych odpadów przemysłowych do wykorzystania w konstrukcjach drogowych. IBDIM, Warszawa, 2004.

[3] SKARZYNSKA, K. Odpady powęglowe i ich zastosowanie w inżynierii lądowej i wodnej, Akademia rolnicza im. H. Kołłątaja, 1997, ISBN 83-86524-26-X.

[4] SYBILSKI, D. Zastosowanie odpadów gumowych w budownictwie drogowym. Przegląd budowlany, nr 5, 2009, pp. 37-44.

[5] LO PRESTI, D. Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review. Construction and Building Materials, Vol. 49, pp. 863-881, 2013.

[6] PN – EN 450-1:2012. Fly Ash for concrete – Part 1: Definition, specification and conformity criteria

[7] PN-S-06103:1997. Drogi samochodowe -- Podbudowa z betonu popiołowego, PKN

[8] PN-B-06250:1988. Beton zwykły, PKN.

[9] PN-EN 13286-2:2010 Unbound and hydraulically bound mixtures - Part 2: Test methods for laboratory reference density and water content - Proctor compaction.

[10] SAS, W. and A. GŁUCHOWSKI. Methods of determination of the modulus of elasticity (E and Mr) from the repeated loading tests CBR. Scientific Review – Engineering and Enviromental Sciences No 57, 2012, pp. 171-181.

[11] WT-5: 2010. Wymagania techniczne. Mieszanki związane spoiwem hydraulicznym do dróg krajowych, GDDKiA.