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Experimental Investigation of the Effects of using Waste Rubber Ash on Mechanical Properties of Plain Concrete

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ABSTRACT

In this study, the effects of using rubber ash on the mechanical properties of plain concrete were experimentally investigated. The main purpose of this study was to determine the proper fraction of rubber ash to be utilized in concrete by investigating the mechanical properties of concrete such as elasticity modulus, compressive strength, tensile strength, bending strength, and fresh concrete slump. Four different fractions of rubber ash (2.5, 5, 7.5 and 10% of cement weight) were added to the concrete mixture. Based on the results achieved from the tests conducted on the specimens, it could be deduced that adding rubber ash to concrete considerably increased compressive and bending strength and reduced the slump flow. It also increased tensile strength and elasticity modulus at a lower level.

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NOMENCLATURE

TRA	Tire Rubber Ash

1. INTRODUCTION

For several years, concrete has been known as a compatible material that is generally used in the construction industry. Concrete has some weaknesses like its brittle nature that limits its usage in some conditions. There have also been some concerns about the coexistence of concrete with nature and its environmental impacts. For this reason, many attempts have been made at making durable concrete with no need for repair and rehabilitation with the lowest environmental impacts [1-3].

Today, the development of the auto industries in the world has increased the production of tires and rubbers and has led to a tremendous increase in the utilization of polymeric materials. The low decomposition rate and failure in the recycling process of tire rubber have been a huge problem for the environment. Thus, it is necessary to use optimally these wastes [4].

Direct replacement of the rubber in the concrete as fine or coarse aggregates is one of the solutions proposed by researchers [5, 6]. It was found that if the materials are produced in smaller sizes, the bonds they make with other phases around them would be much stronger than when they are produced in larger sizes [7]. However, the results from previous studies indicate the fact that the direct use of rubber will severely reduce the strength of the concrete [8-14].

Al-Akhras and Smadi [15] added tire rubber ash (TRA) as filler in the concrete mortar. By conducting some tests, they resolved that by adding TRA, the air content of the mortar reduces, both primary and secondary setting times of concrete increase, and its resistance against freeze-thaw cycles increases as well. They declared that the reason for such improvement in the mortar properties is due to the filling role of rubber ash and the considerable amount of silica in this material.

In addition, Tavakoli and Rahimpour [16] investigated the influence of rubber ash on shotcrete concrete. The results of their research indicated that the tensile strength of concrete is simultaneously increased by increasing the content of rubber ash. The presence of

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sulfone links make the silica network more orderly and increase the cement matrix strength. According to their results, the high fineness of rubber ash and its filler role causes an increase in concrete strength [17].

It is worth mentioning that in Tavakoli et al. [16]'s research, the effect of rubber ash on the durability of concrete containing rubber ash (with soda solution and salt ink for 70 days) was investigated, and the results showed that the durability of concrete containing rubber ash is good.

Senin et al. [18] investigated and compared the physical and chemical properties of rubber ash and sand. By comparing the results obtained from the Scanning Electron Microscope (SEM) test, they declared that the surface of rubber ash is more irregular than sand and this improves the cement matrix. Furthermore, rubber ash has nano dimensions that properly fill the voids in the mortar of the concrete. Generally, they concluded that the rubber ash is a proper replacement for sand in the concrete.

Although there have been several investigations on the effects of TRA on the properties of concrete; to the authors' knowledge, there have been no experimental studies made to investigate the mechanical properties of concrete specimens with different percentages of rubber ash used as filler.

Four different percentages of cement weight were selected for adding TRA to the concrete mixture (2.5, 5, 7.5, and 10%). In this study, while two other percentages were only used for the compressive strength test (15% and 20%) to determine the optimum percentage of TRA in concrete. Tests were carried out on fresh concrete as well as cubic, cylindrical and rectangular specimens and slump-flow, elasticity modulus, compressive strength, tensile strength, and bending strength were analyzed. Some valuable results were obtained from the analysis.

2. EXPERIMENTAL STUDY

2. 1. Materials

2. 1. 1. Cement In this study, ordinary type 2 Portland cement was used. Table 1 presents the primary properties of this material.

2. 1. 2. Aggregates For this test, a coarse aggregate with a maximum dimension of 12.5 mm and fine aggregate with a maximum dimension of 4.75 mm and sand equivalent (SE) of 96%, and a fineness modulus of 3.1 was adopted. The gradation curves for coarse and fine aggregates are depicted in Figure 1 and are both in the range of the ASTM standard [19]. In addition, the water absorption capacity of the aggregates is shown in Table 1.

TABLE 1. Physical and mechanical properties of cement, aggregates, rubber ash

Analysis	Results
Setting time (min) of OPC cement	Initial time – 120
	Final time – 230
	3 Days – 24
Compressive strength (MPa) of OPC cement	7 Days – 34
	28 Days – 43
Water absorption of coarse aggregate	0.5%
Water absorption of fine aggregate	0.5%
Water absorption of rubber ash	0.3%

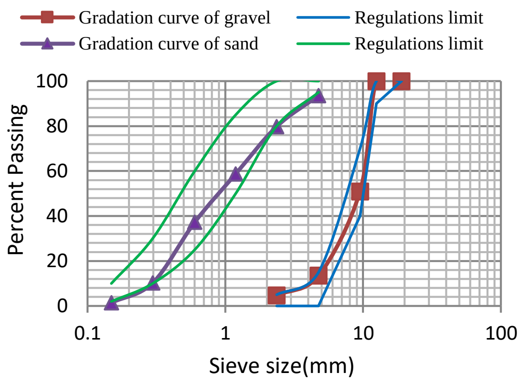

Figure 1. Gradation curve for used gravel and sand

2. 1. 3. Waste Tire Rubber Ash This is a black material with a relative density of 0.455. The first step in this study was to determine the optimum temperature at which rubber should be burned. This was necessitated by the fact that there are few studies about waste tire rubber ash as an additive in concrete. For this purpose, the compressive test was conducted on 28-day cubic specimens containing rubber ashes that were burnt at temperatures from 350 to 900°C, and from the results, the optimum temperature was obtained.

2. 2. Mixture Proportions A concrete mix design with a water to cement ratio of 0.61 was obtained and based on ACI C211 guideline, rubber ash was added as an additive to concrete with the fractions of 2.5, 5, 7.5, and 10% of cement weight, respectively (Table 2). The fractions of 15% and 20% were only tested under the compressive strength test.

2. 3. Specimens Properties For conducting compressive tests, fifteen cubic concrete specimens with a cross-section of 100x100mm were fabricated. In addition, fifteen other cylindrical specimens with a

TABLE 2. Mixing proportions of concrete (kg/m^3)

Design name	Tire rubber ash (Percent of cement weight)	Cement	Water	Gravel	Sand
Ref	-	363	222	924	1000
TRA2.5	2.5%	363	222	924	1000
TRA5	5%	363	222	924	1000
TRA7.5	7.5%	363	222	924	1000
TRA10	10%	363	222	924	1000
TRA15	15%	363	222	924	1000
TRA20	20%	363	222	924	1000

diameter of 150 mm and a height of 300 mm were made for the tensile strength test (Figure 2).

To evaluate the bending strength parameter, fifteen unreinforced concrete specimens with a cross-section of 100x100 mm and a height of 840 mm were fabricated. Table 3 describes the number and the type of specimens used for each test.

2. 4. Loading Program and Apparatus To conduct the compressive test, 21 cubic specimens were applied to compressive loading according to the ASTM C39 standard. As 7 different mix designs were selected for this study, each mix design was tested three times and from the average of the results, the amount of compressive strength was obtained. The loading apparatus used for the compressive strength test in this study is presented in Figure 3.

For the tensile strength test, the Brazilian tensile strength test was conducted on 15 cylindrical specimens according to ASTM C496. The loading apparatus and tested specimens for this test are depicted in Figure 4.

UTM[1] as completely depicted in Figure 5 is the loading apparatus used for the bending strength test. According to the ASTM C78 standard, 15 grooved concrete beam specimens were applied to bending loading.

TABLE 3. Details and properties of the test specimens.

Type of test	Number of specimens	Shape of specimen	Dimension (mm)
Compressive strength	21	Cubic	100x100x100
Tensile strength	15	cylindrical	300x150
Bending strength	15	Grooved beam	100x100x840
Temperature determination of TRA	9	Cubic	100x100x100

Figure 2. The process of making cubic specimens for compressive tests

Figure 3. Loading apparatus for the compressive strength test

Figure 4. Loading apparatus and specimens for the tensile strength test

3. DISCUSSION AND RESULTS

3. 1. Ash FTIR Analysis The FTIR spectrum of concrete with rubber as is illustrated in Figure 6. Results from FTIR spectroscopic tests showed the presence of a sulfone peak in the concrete containing rubber ash.

3. 2. Slump The slump-flow test was conducted on fresh concrete for different mix designs according to ASTM C143 standard. Figure 7 indicates the effect of

[1] Hydraulic Universal Testing Machine

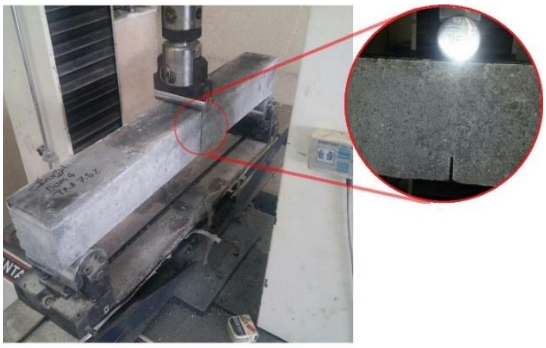

Figure 5. Test setup of bending strength test (Universal testing machine)

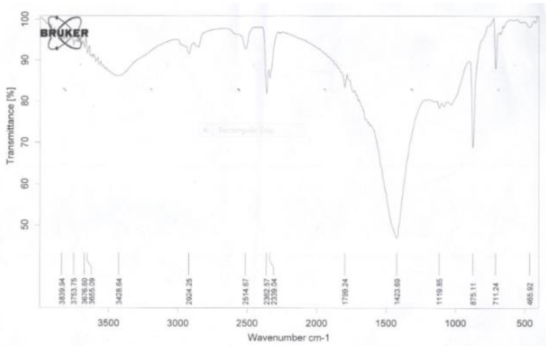

Figure 6. FTIR Images of spectrometric test of concrete with rubber ash

adding rubber ash on the slump of fresh concrete. It could be claimed from the obtained values that the slump of fresh concrete is reduced by increasing the percentage of rubber ash. The slump for the reference mix design was 110 mm but for concrete containing 10% rubber ash, it was measured to be about 30 mm.

For concrete mix designs of TRA2.5, TRA5, TRA7.5, and TRA10, the reduced percentage of a slump than reference mix design is equal to 18, 32, 45, and 73%, respectively. The reason for this increment in the slump amount is due to fine particles of rubber ash, its higher specific surface, and its filler role in concrete. The chemical properties of rubber ash are such that it could result in severe adhesion in the concrete.

3. 3. Elasticity Modulus The elasticity modulus test was conducted on concrete cylindrical specimens with dimensions of 150x300 mm by the installation of a strain gauge on them. Since human errors could be involved during the calculation of choral elasticity modulus, secant elasticity modulus has also been calculated for all mix designs. The results obtained from this test are indicated in Figure 8.

The results obtained from the elasticity modulus test indicated that by increasing the rubber ash content in the specimens, the modulus of elasticity would have an ascending trend such that for a specimen with 10% rubber ash, the choral elasticity modulus would increase up to 14% and secant elasticity modulus would also increase up to 15% than the Ref mix design.

3. 4. Compressive Strength In this study, the compressive strength of concrete is presented as the determinative parameter. Therefore, two more fractions (15% and 20%) of rubber ash were tested in this section for a comprehensive result and to reach an optimum percent of rubber ash in concrete. The test was conducted on cubic specimens of 100 mm with two setting periods of 7 and 28 days. Figure 9 indicates the obtained average values for the compressive strength of different fractions of rubber ash. By increasing the rubber ash up to 15% and 20%, the compressive strength will have a descending trend. The obtained amounts of compressive strength for both 7 and 28-day specimens and every mix design are listed in Table 4.

For the different fractions of rubber ash from 2.5 to 20%, the amount of increase in compressive strength compared to the Ref mix design for specimens of 7 days was 6.6, 13, 22, 38, 20, and 13% and for specimens of 28 days were 8, 16, 22, 35, 21.5 and 9%, respectively. The reason for this increase in compressive strength is that the fine particles of rubber ash fill the voids between aggregates. Furthermore, these particles have silica in

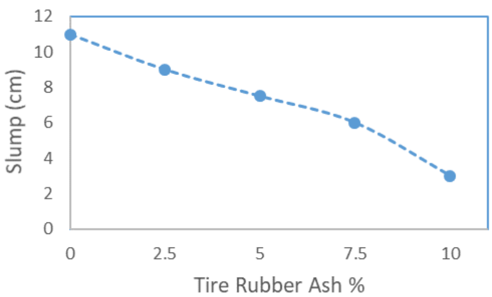

Figure 7. The slump of fresh concrete based on the rubber ash percentage

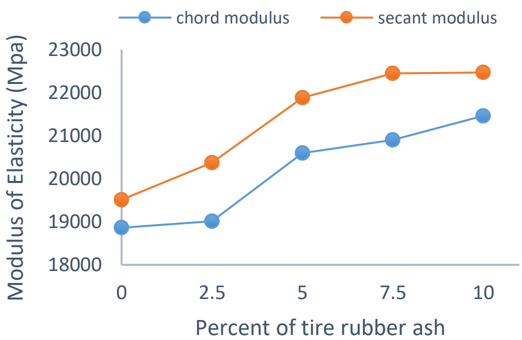

Figure 8. Secant and choral modulus for different percentages of rubber ash

TABLE 4. Compressive strength of 7 and 28-day specimens.

Mix design	7-day compressive strength (Mpa)	28-day compressive strength (Mpa)
Ref	21.95	31.26
TRA2.5	23.4	33.79
TRA5	24.78	36.21
TRA7.5	26.72	38.33
TRA10	30.32	42.2
TRA15	26.3	38
TRA20	24.8	34.1

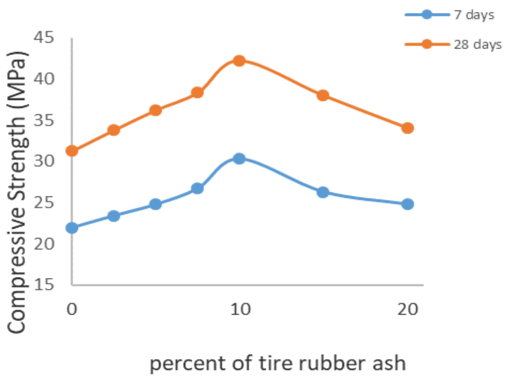

Figure 9. Compressive strength of specimens containing different percentages of rubber ash

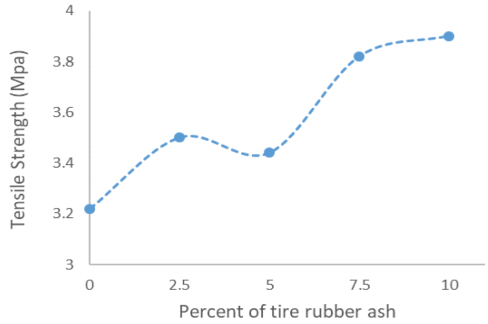

Figure 10. Tensile strength for halving the samples containing different percentages of rubber ash

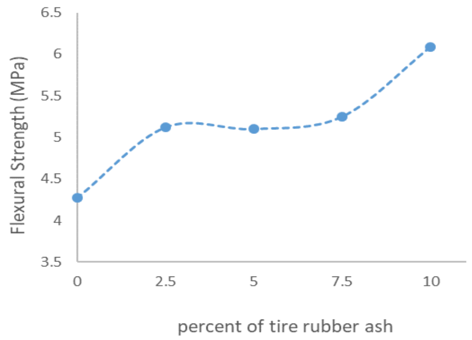

Figure 11. Bending strength for different percentages of rubber ash

their chemical compound which increases the strength of concrete as well. However, by increasing the rubber ash by over 10%, the gap between aggregates would increase more than the normal size thereby causing the concrete's transition zone to become weak and thus, resulting to lower compressive strength.

3. 5. Tensile Strength Brazilian tensile strength test was conducted on 28-day cylindrical specimens (150 × 300 mm) and the results obtained from this test are depicted in Figure 10. As demonstrated in the diagram, the tensile strength of the specimens increased with the increase of rubber ash. As for TRA10, the tensile strength of the concrete increased up to 21% than the to mix design.

By increasing the percentage of rubber ash, the transition zone of the concrete will be improved causing the tensile strength of the specimens to increase. Adding rubber ash to a concrete mixture also prevents cracks and micro-cracks propagation and as a result, concrete would be promoted against tensile strength.

3. 6. Bending Strength The bending strength test was conducted on beam specimens with dimensions 100× 100× 500mm based on ASTM C293. Figure 11 indicates the effects of adding different fractions of rubber ash on the flexural strength of unreinforced beam specimens. When up to 10% of rubber ash was added to the concrete, the bending strength of the concrete increased from 4.27 to 6.09 Mpa.

By increasing the rubber ash in concrete specimens up to 2.5, 5, 7.5, and 10%, the bending strength of the concrete increased to 20, 19.5, 23, and 42%, respectively compared to reference mix design. The increase in bending strength of the specimens is due to the co-operation of the physical and chemical properties of rubber ash such that the physical properties of this material cause the existing voids in the concrete to be filled. Thus, it results in denser concrete with a strong transition zone. Furthermore, the chemical properties of rubber ash are due to the presence of silica. This is the main factor responsible for the increase in concrete strength as well as the creation of Sulfone bonds in concrete, causing the regularity of the silica network and increasing the matrix strength of the cement.

4. CONCLUSION

In this study, experimental evaluations were performed to evaluate the effects of adding waste tire rubber ash to concrete by measuring the mechanical properties of the specimens. Based on the results obtained, the following conclusions can be drawn:

Increasing the percentage of rubber ash, leads to a lower slump for fresh concrete. As for the TRA 10% mix design, there would be a decrease of up to 73% in the slump.

The choral and secant elasticity modulus of the concrete will have ascending trend by increasing the rubber ash content such that by adding 10% rubber ash to concrete, the choral elasticity modulus increased up to 14%, and the Secant elasticity modulus increased up to 15%.

During setting periods of 7 and 28 days, the compressive strength of the specimens increased by increasing the content of rubber ash up to 10%. However, by increasing the rubber ash by more than 10%, the concrete strength would have a descending trend. It can be stated that 10% of rubber ash is the optimum amount of rubber ash that shows the best performance of concrete.

The bending strength of the concrete indicates an ascending trend by increasing the rubber ash content such that by increasing TRA up to 10%, the bending strength of concrete increases up to 42% more than the Ref mix design.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Darwin, D., Mindess, S. and Young, J., *Concrete*. 2003, Prentice-Hall, Upper Saddle River, NJ.
2. Tavakoli, H., Mahmoudi, S., Goltabar, A. and Jalali, P., "Experimental evaluation of the effects of reverse cyclic loading rate on the mechanical behavior of reinforced scc beams", ***Construction and Building Materials***, Vol. 131, (2017), 254-266. https://doi.org/10.1016/j.conbuildmat.2016.11.043
3. Aiello, M.A. and Leuzzi, F., "Waste tyre rubberized concrete: Properties at fresh and hardened state", ***Waste Management***, Vol. 30, No. 8-9, (2010), 1696-1704. https://doi.org/10.1016/j.wasman.2010.02.005
4. Nehdi, M. and Khan, A., "Cementitious composites containing recycled tire rubber: An overview of engineering properties and potential applications", ***Cement, Concrete and Aggregates***, Vol. 23, No. 1, (2001), 3-10.
5. Yilmaz, A. and Degirmenci, N., "Possibility of using waste tire rubber and fly ash with portland cement as construction materials", ***Waste Management***, Vol. 29, No. 5, (2009), 1541-1546. https://doi.org/10.1016/j.wasman.2008.11.002
6. Gupta, T., Chaudhary, S. and Sharma, R.K., "Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate", ***Construction and Building Materials***, Vol. 73, (2014), 562-574. https://doi.org/10.1016/j.conbuildmat.2014.09.102
7. Oriakhi, C.O., "Polymer nanocomposition approach to advanced materials", ***Journal of Chemical Education***, Vol. 77, No. 9, (2000), 1138. https://doi.org/10.1021/ed077p1138
8. Siringi, G.M., "Properties of concrete with tire derived aggregate and crumb rubber as a ligthweight substitute for mineral aggregates in the concrete mix", (2012). Ph.D. Dossertations, University of Texas, USA.
9. Khatib, Z.K. and Bayomy, F.M., "Rubberized portland cement concrete", ***Journal of Materials in Civil Engineering***, Vol. 11, No. 3, (1999), 206-213. https://doi.org/10.1061/(ASCE)0899-1561(1999)11:3(206)
10. Turatsinze, A., Bonnet, S. and Granju, J.-L., "Mechanical characterisation of cement-based mortar incorporating rubber aggregates from recycled worn tyres", ***Building and Environment***, Vol. 40, No. 2, (2005), 221-226. https://doi.org/10.1016/j.buildenv.2004.05.012
11. Li, G., Garrick, G., Eggers, J., Abadie, C., Stubblefield, M.A. and Pang, S.-S., "Waste tire fiber modified concrete", ***Composites Part B: Engineering***, Vol. 35, No. 4, (2004), 305-312. https://doi.org/10.1016/j.compositesb.2004.01.002
12. Yung, W.H., Yung, L.C. and Hua, L.H., "A study of the durability properties of waste tire rubber applied to self-compacting concrete", ***Construction and Building Materials***, Vol. 41, (2013), 665-672. https://doi.org/10.1016/j.conbuildmat.2012.11.019
13. Li, L., Ruan, S. and Zeng, L., "Mechanical properties and constitutive equations of concrete containing a low volume of tire rubber particles", ***Construction and Building Materials***, Vol. 70, (2014), 291-308. https://doi.org/10.1016/j.conbuildmat.2014.07.105
14. Richardson, A.E., Coventry, K.A. and Ward, G., "Freeze/thaw protection of concrete with optimum rubber crumb content", ***Journal of Cleaner Production***, Vol. 23, No. 1, (2012), 96-103. https://doi.org/10.1016/j.jclepro.2011.10.013
15. Al-Akhras, N.M. and Smadi, M.M., "Properties of tire rubber ash mortar", ***Cement and Concrete Composites***, Vol. 26, No. 7, (2004), 821-826. https://doi.org/10.1016/j.cemconcomp.2004.01.004
16. Tavakoli, H. and Rahimipour, M., "Effect of ash tires on mechanical properties and durability of concrete shotcrete and comparison with concrete shotcrete containing nano-silica", (2015).
17. Pavia, D.L., Lampman, G.M., Kriz, G.S. and Vyvyan, J.A., "Introduction to spectroscopy, Cengage learning, (2014).
18. Senin, M.S., Shahidan, S., Leman, A.S. and Hannan, N.I.R.R., "Analysis of physical properties and mineralogical of pyrolysis tires rubber ash compared natural sand in concrete material", in IOP Conference Series: Materials Science and Engineering, IOP Publishing. Vol. 160, (2016), 012053.
19. Conshohocken, P., "Astm international", Atanasova, B., Langlois, D., Nicklaus, S., Chabanet, C. et Etiévant, P, (2004).

Persian Abstract

چکیده

در این مطالعه اثرات استفاده از خاکستر لاستیک بر خواص مکانیکی بتن به صورت تجربی بررسی شد. هدف اصلی این مطالعه تعیین مقدار مناسب خاکستر لاستیک مورد استفاده در بتن، با بررسی خواص مکانیکی بتن مانند مدول الاستیسیته، مقاومت فشاری، مقاومت کششی، مقاومت خمشی و اسلامپ بتن تازه بود. چهار بخش مختلف خاکستر لاستیک (۲.۵٪، ۵٪، ۷.۵٪ و ۱۰٪ بر اساس وزن سیمان) به مخلوط بتن اضافه شد. بر اساس نتایجی که از آزمایش بر روی نمونه ها به‌دست‌آمد، می‌توان استنباط کرد که افزودن خاکستر لاستیک به بتن به طور قابل‌توجهی باعث افزایش مقاومت فشاری و خمشی بتن شد و اسلامپ بتن را نیز کاهش داد. همچنین مقاومت کششی و مدول الاستیسیته با افزایش میزان خاکستر لاستیک در بتن در سطح پایین تری افزایش یافت.