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Impact on concrete properties using e-plastic waste fine aggregates and silica fume

Introduction

Various kinds of plastic are currently being produced from the new lifestyle and this has led to a huge surplus disposal problem (Batayneh et al. 2007). Plastic possess particular polymer characteristics. It is formed by the combination of hydrocarbon monomers that

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allows it to be used in different industries including: food packing, mineral water gallons, polythene bags, electrical machines etc. in routine life. In the present scenario, plastic has become essential in everyday life (Williams and Williams 1997). Thus the demand of plastic products is increasing on a regular basis (Suganthy et al. 2013). Plastic disposal leads to poor soil fertility, reduction in moisture percolation, release of unsafe noxious gases, health deathtraps to animals and birds consuming plastic waste as a misguided meal, lessening in the flow of waste water due to land fill and the contamination of groundwater due to the leaching of chemicals from these waste composites. Thus, it is very much damaging to the environment all over the world (Sambhaji 2016).

Concrete is the most widely used material in the world. After water, concrete is the second most used material in the earth. Looking for aggregates for concrete and to dispose of the e-waste from several sources is the present worry. The manufacture of concrete is increasing day by day. The demand of aggregates in return is also increased. This is distressing our environment day by day as the consumption of the natural resources is increased.

Concrete is the utmost extensively used and adaptable construction material which is normally used to resist compressive forces. Literature supports that plastic disposal can be used in concrete as a partial modification of fine aggregates. The consumption of plastic waste in the construction industry has found two benefits, firstly, environmental influences caused by the discarding of the waste can be reduced up to a certain limit and secondly, the cost-effective impact of these wastes are presented at huge number in low rate (Sadiq and Khattak 2015).

1. E-plastic waste and silica fume in concrete

When e-plastic attains its life, it is either recycled or dumped. E-plastic can be recycled two or three times, after this it is then dumped in the earth. This pollutes the environment. The manufacture of e-plastic in the world is around 50 million metric tons. Out of this only 10-20 % is recycled, the rest is dumped which is not an eco-friendly solution. In this condition instead of recycling it repeatedly, if it is used to prepare fine aggregates for concrete, it will be beneficial to the construction industry.

Electronic waste (e-waste) is one of the new waste materials that are emerging in the concrete industry. The disposal of enormous quantities of e-waste material can be reused in the concrete industry where it also solves the dumping problem. Hence, the recycling and reusing of e-waste in the concrete industry is measured as the most real-world application. E-waste is a serious pollution problem for human beings and also the environment. Therefore, some options are needed to be considered, particularly on recycling material units. E-waste is an unevenly discarded excess, broken, electrical or electronic device. Instant technology change and low initial cost have led to a fast-growing surplus of e-waste around the world. A large amount of e-waste needs to be disposed per year. E-waste contains numerous types of ingredients and chemicals producing serious human health and environment problems if not handled properly.

Alagusankareswari et al. (2016) replace fine aggregates using e-waste as a replacement material. Control mix, E10, E20, E30 were used to observe the rate of strength achievement. The results demonstrated that the compressive strength and split tensile strength of concrete containing the e-waste ware slightly lower than the control mix. According to them, e-waste can be consumed as light weight aggregate because the self-weight of the concrete decreases. According to Gawatre et al. (2015) an addition of 7.5% e-waste fine aggregates gives the ideal compressive strength while compressive strength decreases when e-waste replaces more than 15% fine aggregates.

The same was observed by Suchithra et al. (2015) that after 15 % replacement compressive strength decreases. Experiments revealed that flexural strength has a noticeable effect as compared to split tensile strength. In addition, the durability to sulphate attack and chloride attack increases with e-waste addition.

Nagajothi and Felixkala (2014) observed a two-fold increase in compressive strength by the addition of 2.5% e-fiber waste to the concrete mix. The experimental setup by Arora and Dave (2013) was limited to the replacement of fine aggregates by e-waste in mortars. They concluded that 4% replacement provides an acceptable strength. Gautam (2012) replaced fine aggregates with glass waste. At 28 days strength, 20% glass waste replacement performed very well. A marginal decrease in strength was observed at 30 and 40 % replacement. Ideal replacement was found to be 10%. Lakshmi and Nagan (2010) observed good strength by replacing the course aggregates with e-waste material ranging from 0 to 30%. In addition, the fly ash improved the controlled and e-waste concrete strength. Chen (2006) observed that e-waste particles increase the crack resistance of concrete.

Sunil Ahirwar (2016) stated that the workability of concrete increases with increase in the e-waste material. The addition of fly ash with e-waste increases the workability of a conventional concrete mix while the compressive strength decreases with e-waste material. Concrete industries consume a gigantic quantity of cement and for the production of cement and a huge amount of energy is required, which emits toxic gases. Thus, cutting down the consumptive use of cement in the construction industry is required to achieve an efficient environment (Meena et al. 2018). The literature study shows that silica fume can also be used as a cement modification in concrete construction and can significantly enhance the performance of concrete (Kumar 2014).

This study determines the effect of the partial replacement of e-plastic as fine aggregates in concrete mixtures and studies the effect of silica fume on mechanical properties of e-plastic concrete. The effect of the partial replacement of e-plastic fine aggregates on the workability of concrete has been determined as well. The 28 day compressive, tensile, flexural strength of concrete with a 0, 5, 10, 15, 20% replacement of e-plastic fine aggregates was achieved. Moreover, the effect of an addition of 5 and 10% silica fumes on the strength of concrete was determined.

2. Methodology

E-plastic waste is collected from a local vendor in Rawalpindi and after that it is then shred into pieces by a crushing machine so that it can pass through sieve No. 4 and can be used in concrete as a partial replacement of fine aggregate. The ratio used in this study is 1:1.5:3 and w/c ratio is 0.5. Concrete mixes were produced by replacing 0, 5, 10, 15 and 20% as a fine aggregate and a further silica fume was added to the concrete for strength achievement as a 5 and 10% addition. Cylinders and molds were casted for compressive, flexural and tensile strength determination at 28 days.

2.1. Materials

The following section explains the materials and mix combinations used in the study.

2.2. Cement

Ordinary Portland cement from the Fouji Cement Company Limited (FCCCL) brand which is easily available in this area and is being used in the construction projects in this region in compliance with the standards, is used in the present study. The properties of the cement provided by the manufacturer are given in Table 1.

Table 1. Physical properties of ordinary Portland cement by FCCCL (2018)

Tabela 1. Właściwości fizyczne zwykłego cementu portlandzkiego

Properties	FCCL Results	Standard Requirement ASTM C-150
Initial Setting time (min)	110	45 (Min)
Final Setting time (min)	180	375 (Max)
3-day Compressive Strength (psi)	3 259	1 740 (Min)
7-day Compressive Strength (psi)	5 039	2 760 (Min)
28-day Compressive Strength (psi)	5 844	–

2.3. Fine aggregates

Natural sand from Lawrencepur is used in the study. This sand is in compliance with the standards and is being used in a lot of construction projects of this region. Table 2 presents the physical properties of the fine aggregates.

Table 2. Physical properties of fine aggregate

Tabela 2. Właściwości fizyczne drobnego kruszywa

Test name	Result
Fineness Modulus	2.2
Bulk Specific Gravity	2.62 (specific gravity range: 1520 to 1680 kg/m^3)

2.4. Coarse aggregates

Crushed rocks from the Margalla quarry were used in the present study. The size of coarse aggregates used was 3/4 down. These aggregates are reliable as they are being used in a lot of construction projects in this region. Table 3 presents the physical properties of the coarse aggregates.

Table 3. Physical properties of coarse aggregate

Tabela 3. Własności fizyczne kruszywa grubego

Test name	Results
Maximum Size	19 mm
Fineness Modulus	8.4
Bulk Specific Gravity	2.68 (specific gravity range: 1520 to 1680 kg/m^3)
Water Absorption	0.317%

2.5. E-plastic fine aggregate

An experimental study is made on the consumption of e-waste particles as fine aggregates in concrete with a percentage replacement ranging from 0–20%. This e-plastic waste was purchased from the local vendor in Rawalpindi. It was taken to a crushing plant where it was crushed to fine aggregates. Only aggregates passing sieve No. 4 were used in concrete. Table 4 presents the physical properties of the coarse aggregates.

Table 4. Physical properties of E-plastic fine aggregate

Tabela 4. Właściwości fizyczne drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych

Test name	Results
Type	Crushed
Fineness Modulus	5.24
Bulk Specific Gravity	1.09
Water Absorption	0%

2.6. Silica fume

MS-85 (16) is a concrete additive particular for high performance concretes. Micro Silica is also known as Silica fume. It changes the porous structure of the concrete, increase the density of concrete, increase the resistance to any type of external impact and extend the lifetime of the structure. Silica fume is used in addition to cement. Mix min. 30 seconds before adding water and 90 seconds after adding it. Experience has shown that mixing time should be extended to 180 seconds in order to obtain homogenous uniformity and stable quality. Silica fumes were used in 5 and 10% of cement. The properties of silica fume are given by the manufactures of this product in Table 5.

Table 5. Properties of silica fume MS-85 (16)

Tabela 5. Właściwości pyłu krzemionkowego MS-85 (16)

Type	MS-85 (16)
Colour	dark grey/black powder
SiO_2	>85%
Moisture	<3.0%
Consumption with 100 kg Cement	5–15 kg
Retained on 45-micron sieve	<10%
Bulk Density	600–50 kg/m^3

2.7. Mix design

Table 6 below shows various concrete mixes prepared by using e-plastic as a partial replacement of fine aggregate ranging from 0 to 20%, and silica fume as a partial replacement of cement ranges from 0 to 10 % by weight. The hand mixing technique was used for this research work. The mix proportion for the control mix was 1:1.5:3 with w/c ratio of 0.5.

Table 6. Mix details (w.r.t % age)

Tabela 6. Szczegóły mieszanki (wartości procentowe)

Mix	Designation	Cement (%)	Silica (%)	Coarse (%)	Fine (%)	Plastic (%)	Water (%)
1	P0S0	100	0	100	100	0	100
2	P5S0	100	0	100	95	5	100
3	P10S0	100	0	100	90	10	100
4	P15S0	100	0	100	85	15	100
5	P20S0	100	0	100	80	20	100
6	P0S5	100	5	100	100	0	100
7	P5S5	100	5	100	95	5	100
8	P10S5	100	5	100	90	10	100
9	P15S5	100	5	100	85	15	100
10	P20S5	100	5	100	80	20	100
11	P0S10	100	10	100	100	0	100
12	P5S10	100	10	100	95	5	100
13	P10S10	100	10	100	90	10	100
14	P15S10	100	10	100	85	15	100
15	P20S10	100	10	100	80	20	100

3. Results and discussion

This section presents the test results of fresh and hardened concrete mix prepared with the addition of e-plastic as a partial replacement of fine aggregate and silica fume as a partial replacement of cement in comparison to the control mix. The workability, density of concrete Compressive, Flexural and Split tensile strengths were determined.

3.1. Compressive strength test results

The bar chart shown in Figure 1 reflects the comparison of compressive strength of concrete mix prepared with a varying percentage of e-plastic as a partial replacement of fine aggregate and with a varying percentage of silica fume as a replacement for cement. The figure depicts that the compressive strength of control concrete mix after 28 days is 37.4 MPa, whereas the strength of concrete mix with 20% e-plastic without silica fume is 28.9 MPa, which is 23% less as compared to the control mix. The overall trend reflects that the compressive strength of concrete decreases with increase in e-plastic percentage, this decrease in strength of concrete is due to the non-adhesive nature of plastic aggregates with cement content. However, the addition of silica fume as a partial replacement of cement increases the compressive strength. The optimum compressive strength achieved at a 5% addition of e-plastic along with the addition of 10% silica fume and an approximately similar compressive strength is attained as achieved in the control mix.

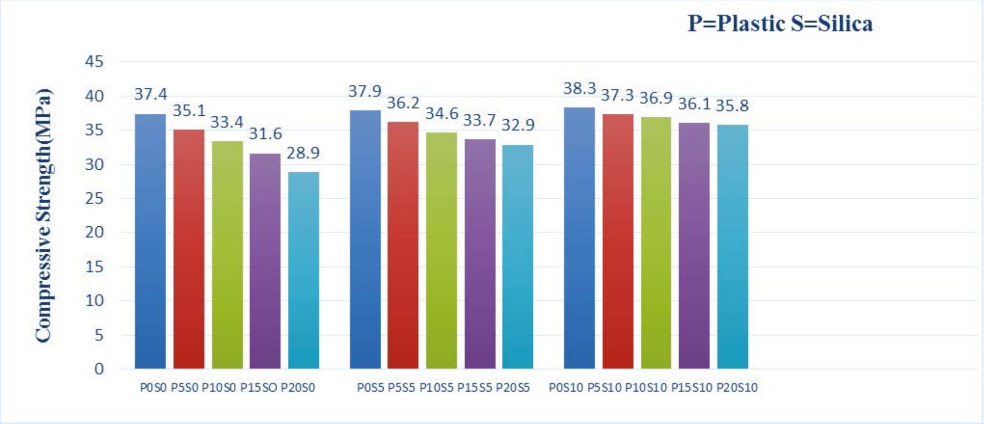

Fig. 1. Comparison of the compressive strength of concrete mixtures prepared with varying percentages of e-plastic fine aggregate

Rys. 1. Porównanie wytrzymałości na ściskanie mieszanek betonowych przygotowywanych z różnym udziałem procentowym drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych

The comparison of the compressive strength of concrete mixes prepared with different percentages of silica fume range from 0 to 10 % shown in Figure 2. The results revealed that the addition of silica fume increases the compressive strength of concrete and the optimum strength is achieved at 10% replacement of cement content, however strength decreases with an increase in the percentage content of e-plastic as a partial replacement of fine aggregate. The result shows that the addition of e-plastic waste will be considered effective with the addition of silica fume, as silica fume is considered as a highly pozzolanic material and produces calcium silicate hydrate (C-S-H) which results in the increased compressive strength of concrete.

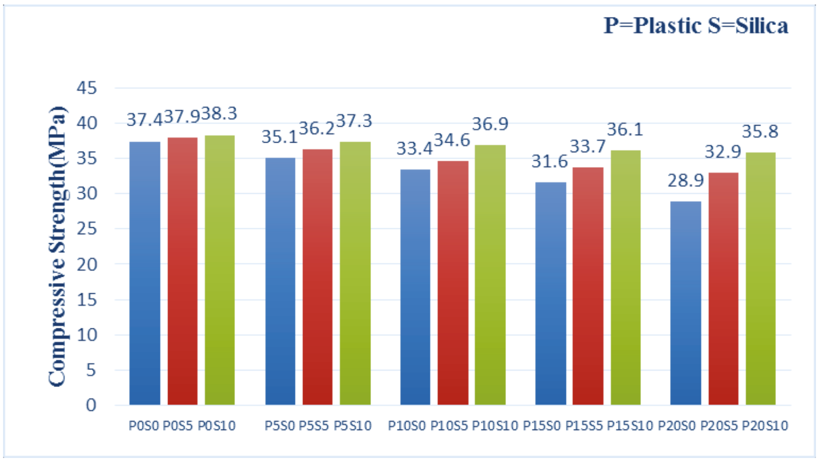

Fig. 2. Comparison of compressive strength of the concrete mixtures prepared with varying percentages of silica fumes

Rys. 2. Porównanie wytrzymałości na ściskanie mieszanek betonowych przygotowywanych z różnym udziałem procentowym pyłów krzemionkowych

3.2. Flexural strength test

Figures 3 and 4 show results of flexural strength of concrete mix with varying percentage of e-plastic and silica fume as a replacement of fine aggregate and cement content.

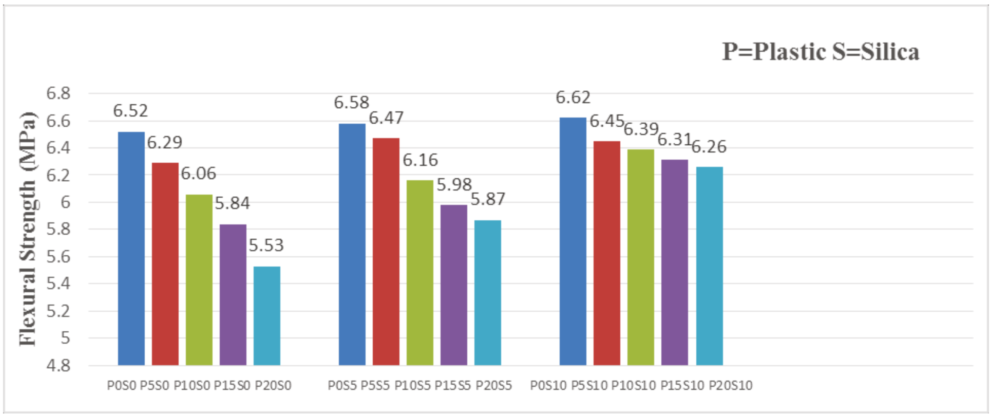

Fig. 3. Comparison of the flexural strength of concrete mixtures prepared with varying percentages of e-plastic fine aggregate

Rys. 3. Porównanie wytrzymałości na zginanie mieszanek betonowych przygotowywanych z różnym udziałem procentowym drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych

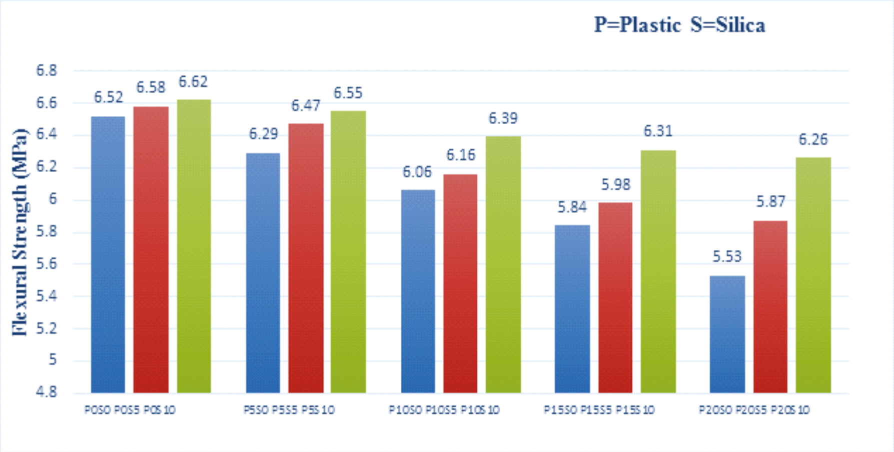

Fig. 4. Comparison of the flexural strength of concrete mixtures prepared with varying percentages of silica fumes

Rys. 4. Porównanie wytrzymałości na zginanie mieszanek betonowych przygotowywanych z różnym udziałem procentowym pyłów krzemionkowych

In comparison to the control mix the flexural strength of concrete mixes decreases with the increase in the addition of e-plastic i.e. 28 days flexural strength of the control mix is 6.52 MPa whereas for the mix with 20% e-plastic and 0% silica fume it is 5.53 MPa which is 18% less compared to the control mix. The addition of silica fume improved the flexural strength for both the controlled mix and the mixes prepared with the varying percentage of e-plastic waste. According to results 28 days flexural strength of control mix is 6.52 MPa whereas with addition of 10% silica fume the strength increased to 6.62 MPa. Similarly flexural strength of concrete mix with 20% plastic waste and 0% silica fume is increased by 13% with the addition of 10% silica fume.

3.3. Split tensile strength test

Figures 5 and 6 show the results of split tensile strength of the control mix and the mix with a varying percentage of plastic aggregate and silica fume. The results revealed tha thte split tensile strength of concrete mixes decreases with the increase in e-plastic content similar to compressive and flexural strength of concrete. The addition of silica fume also increases the split tensile strength of concrete. It was observed that thte addition of plastic aggregates will be beneficial along with the addition of silica fume as a replacement of cement content and produces comparable results.

Fig. 5. Comparison of the split tensile strength of concrete mixtures prepared with varying percentages of e-plastic fine aggregate

Rys. 5. Porównanie wytrzymałości na rozciąganie przy rozłupywaniu mieszanek betonowych przygotowywanych z różnym udziałem procentowym drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych

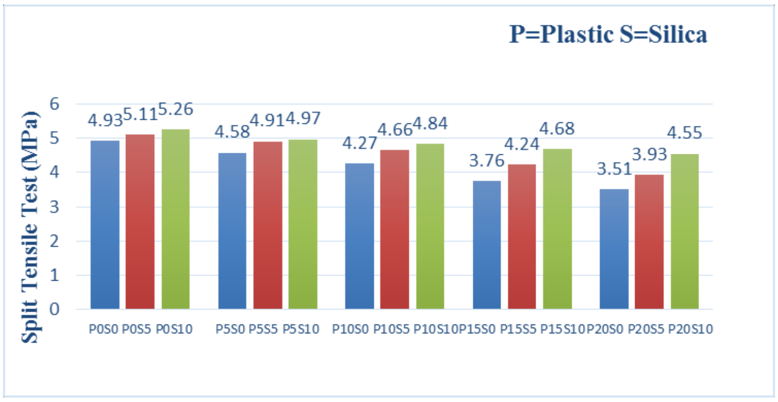

Fig. 6. Comparison of the split tensile strength of concrete mixtures prepared with varying percentages of silica fumes

Rys. 6. Porównanie wytrzymałości na rozciąganie przy rozłupywaniu mieszanek betonowych przygotowywanych z różnym udziałem procentowym pyłów krzemionkowych

3.4. Density test results

The dry density of concrete was determined in kg/m^3. Figure 7 shows that 28-days density of concrete with 0% plastic and 0% silica is 2,598 kg/m^3, whereas with the increase in plastic content, the density of the concrete mix decreases e.g. 2,486 kg/m^3 for the mix with

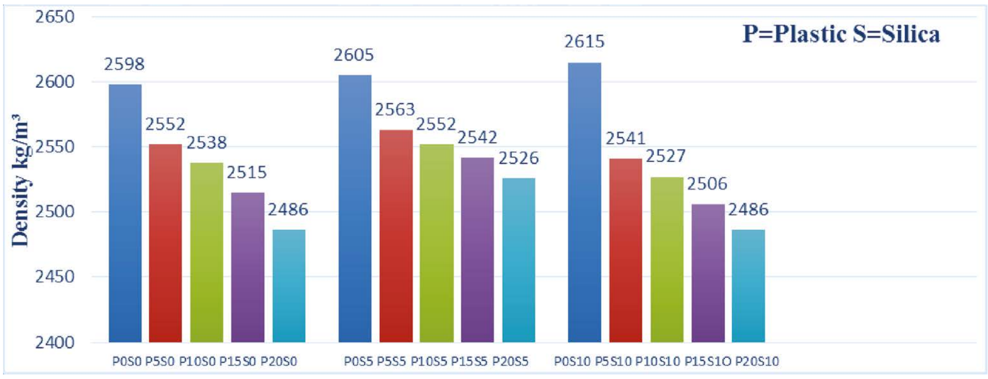

Fig. 7. Comparison of the density of concrete mixtures prepared with varying percentages of e-plastic fine aggregate

Rys. 7. Porównanie gęstości mieszanek betonowych przygotowywanych z różnym udziałem procentowym drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych

20% plastic waste and 0% silica fume. When plastic was increased up to 20%, the density was decreased to 2,486 kg/m^3. The results shows that the light weight nature of plastic aggregates and silica fume produces lightweight concrete.

3.5. Slump test results

The results for the workability of concrete mixes are shown in Figure 8. Figure 8 illustrates that workability of concrete mix increases with the increase in plastic content,

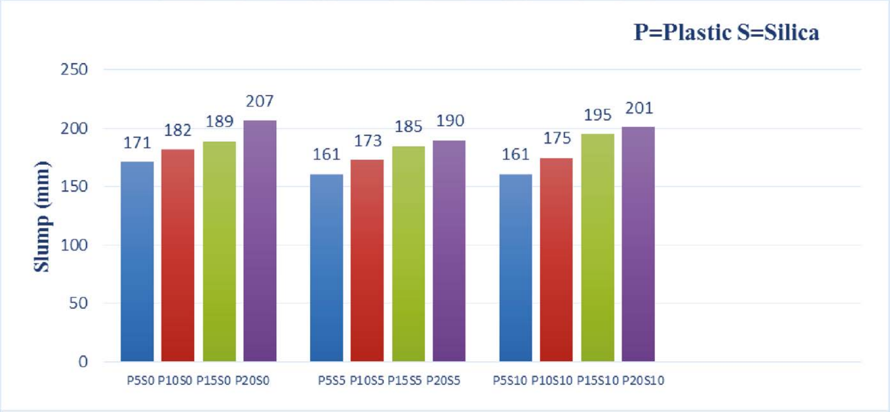

Fig. 8. Comparison of the workability of concrete mixtures prepared with varying percentages of e-plastic fine aggregate

Rys. 8. Porównanie urabialności mieszanek betonowych przygotowywanych z różnym udziałem procentowym drobnego kruszywa z tworzyw sztucznych pochodzących z odpadów elektronicznych however the workability decreases with the addition of silica fume as compare to the control mix. The particle size of silica fume is small and spherical in shape due to which the water demand increases and affects the workability of concrete.

Conclusions and recommendations

Conclusions for this research work are as follows are as follows:

- Suitable proportion of e-plastic can be used as a replacement of natural fine aggregates in concrete giving an eco-friendly solution.
- Workability of concrete mixes increases with the increase in e-plastic content.
- For all mixes 28-day strength (i.e., compressive, flexural and tensile strengths) decreases with the increase in plastic content.
- For a mix with 20% plastic waste as a replacement of fine aggregate, the compressive strength is reduced by 23%.
- For a mix with 20% plastic waste as a replacement of fine aggregate, the flexural strength is reduced by 15%.
- Compressive, flexural and tensile strength of concrete mixes increases with the addition of silica fume.
- For a mix with a 5% e-plastic content and a 10% silica fume, the strength (compressive, flexural and tensile strength) attained is approximately similar to the control mix.
- The addition of plastic waste will be considered beneficial only if silica fume is incorporated in the concrete mix.
- The density of concrete decreases with the increase in e-plastic waste and lightweight concrete is achieved.

The authors recommend the following directions for future work:

- The outcome of adding different mineral admixtures in concrete containing e-plastic fine aggregates can also be considered.
- The use of e-plastic aggregates in concrete as a replacement of natural coarse aggregate is also fascinating for future study.
- Chemical testing and thermal resistance of concrete containing e-plastic aggregates should also be carried out.
- Different percentages of silica fumes can also be used to increase the strength of e-plastic aggregate concrete.

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IMPACT ON CONCRETE PROPERTIES USING E-PLASTIC WASTE FINE AGGREGATES AND SILICA FUME

Keywords

e-waste, fine aggregates, replacement, compressive strength, tensile strength

Abstract

Plastic obtained from the discarded computers, televisions, refrigerators, and other electronic devices is termed as e-plastic waste. E-plastic waste is non-biodegradable waste. This paper focuses to investigate the replacement of fine aggregate with plastic aggregate obtained from e-plastic. The paper presents a detailed comparison of concrete properties (i.e.: compressive strength, tensile strength, flexural strength, density and workability) for normal concrete and concrete containing e-plastic fine aggregates. The testing was conducted according to the ASTM standards. 28-day Compressive, Flexural and Split tensile strengths were determined. In addition to the effect of e-plastic fine aggregate, silica fume is added as an admixture to find the effect on strengths. Authors have performed a compressive, flexural and tensile test of concrete mix with various percentages of e-plastic aggregates (i.e., 0, 5, 10, 15 and 20%) and silica fume (i.e.: 0, 5 and 10%) and concrete densities are also considered. It has been concluded that an increase in the e-plastic fine aggregate results in reduction in densities, compressive, flexural and tensile strength values. However, when we add silica fume to the concrete mixture it leads to strength values similar to the control mixture. The optimum obtained concrete blend contained 5% e-plastic fine aggregates and 10% silica fume. The addition of silica fume in concrete mixtures increases the 28-day compressive, flexural and tensile strengths. Moreover, the density of concrete decreases with the increase in the e-plastic aggregates.

WPŁYW DROBNEGO KRUSZYWA Z TWORZYW SZTUCZNYCH POCHODZĄCEGO Z ODPADÓW ELEKTRONICZNYCH ORAZ PYŁÓW KRZEMIONKOWYCH NA WŁAŚCIWOŚCI BETONU

Słowa kluczowe

tworzywa sztuczne pochodzące z odpadów elektronicznych, kruszywa drobne, zamienniki,
wytrzymałość na ściskanie, wytrzymałość na rozciąganie

Streszczenie

Tworzywa sztuczne uzyskane ze zużytych komputerów, telewizorów, lodówek i innych urządzeń elektronicznych są określane jako tworzywa sztuczne z odpadów elektronicznych. Tworzywa sztuczne z odpadów elektronicznych to odpady nieulegające biodegradacji. Niniejszy artykuł koncentruje się na kwestii zastąpienia drobnego kruszywa kruszywem z tworzyw sztucznych z odpadów elektronicznych. W pracy przedstawiono szczegółowe porównanie właściwości betonu (tj. wytrzymałość na ściskanie, rozciąganie i zginanie, gęstość oraz urabialność) dla normalnego betonu i betonu zawierającego drobne kruszywa z tworzyw sztucznych z odpadów elektronicznych. Testy przeprowadzono zgodnie ze standardami ASTM. Określono 28-dniową wytrzymałość na ściskanie, zginanie i rozciąganie przy rozłupywaniu. Zbadano wpływ drobnego kruszywa z tworzyw sztucznych pochodzącego z odpadów elektronicznych oraz pyłów krzemionkowych na wspomniane właściwości betonu. Autorzy przeprowadzili test ściskania, zginania i rozciągania mieszanki betonowej dla różnych wartości procentowych kruszywa z tworzyw sztucznych z odpadów elektronicznych (tj. 0, 5, 10, 15 i 20%), pyłów krzemionkowych (tj. 0, 5 i 10%) oraz gęstości betonu. Stwierdzono, że zwiększony udział procentowy drobnego kruszywa z tworzyw sztucznych pochodzącego z odpadów elektronicznych prowadzi do zmniejszenia gęstości, wytrzymałości na ściskanie, zginanie i rozciąganie. Jednakże dodanie pyłów krzemionkowych do mieszaniny betonowej pozwala uzyskać parametry wytrzymałościowe podobne do mieszaniny kontrolnej. Otrzymana optymalna mieszanka betonu zawiera 0,5% drobnych kruszyw z tworzyw sztucznych pochodzących z odpadów elektronicznych i 10% pyłów krzemionkowych. Dodatek pyłów krzemionkowych w mieszankach betonowych zwiększa 28-dniową wytrzymałość na ściskanie, zginanie i rozciąganie. Ponadto gęstość betonu zmniejsza się wraz ze wzrostem udziału kruszyw z tworzyw sztucznych z odpadów elektronicznych.