PROPERTIES OF SELF-COMPACTING MORTAR INCORPORATED RECYCLED PLASTIC AGGRIGATES MODIFAIED WITH MICRO SILICA:

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Abstract

This experimental study focuses on the development of self-compacting mortar (SCM) that incorporates recycled plastic aggregate (RPA) as a partial replacement for fine aggregate. The RPA substitution levels tested were 0%, 5%, 10%, 15%, and 20%. To assess the fresh and hardened properties, as well as the durability of the self-compacting mortar with recycled plastic aggregate mixes, silica fume (SF) was added as an admixture at a dosage of 10% of the powder volume to reduce the cement content. The experimental results indicated that the slump flow of self-compacting mortar with recycled plastic aggregate mixes decreased after adding 10% silica fume (SF). The compressive strength and flexural strength of the SCM-RPA mixes decreased with increasing RPA content, while water absorption increased. However, in SCM-RPA-SF mixes, the addition of silica fume yielded the opposite effect by increasing compressive and flexural strength and decreasing water absorption as the RPA content increased. In conclusion, integrating 15% RPA in SCM and SCM-SF mixes can successfully provide comparable strength performance, promote sustainable waste management, conserve natural resources, and contribute to environmental protection.

Keywords: ***Recycled plastic, self–compacting mortar, silica fume, workability***

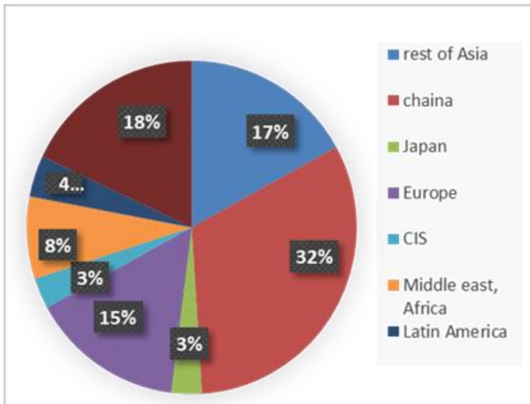
1. Introduction:

Sustainability stands for having sustainable resources for energy and material supply. If all businesses follow ethically sustainable business schemes, we would have a much greener earth than we have today. Unfortunately, global warming has been affecting life on the blue planet, and it has impacted thousands of species' relocation through the ongoing global increase of temperatures in the atmosphere. Of course, Kurdistan has its own share of this devastating climate change, and eco-friendly waste management was not implemented until 2017. Usually, if calculated on a daily basis, Kurdistan has 7500 tons of garbage disposal. Furthermore, there have been multiple approaches to improve and implement eco-friendly waste management in the following cities of Kurdistan: Sulaymaniyah, Duhok, Akre, Amedi, and Takya-Kaka-Mand, they are treating the waste scientifically(zagrosn2019). For example, the Ecosim factory in Sulaymaniyah can recycle 1100–1200 tons of waste daily. It can convert 80% of it into renewable energy (RDF), which is environmentally friendly. RDF energy is reused in cement factories, which can reduce energy consumption by 20–30% instead of using oil energy. And other factories focus on recycling hazardous materials, especially plastic waste (Rudaw 2020). Also, for land filing areas for solid management that to have longer life spans the companies should separate plastic waste. Recycling plastic trash is essential for lowering risk and for developing new, environmentally beneficial ways to recycle plastic.

1.1 Recycled plastic aggregate

Plastic is a polymeric material that can be molded into different shapes and products like (bottles and plastic bags, etc. This property of plasticity, with low density, and low electrical conductivity, transparency, toughness, and low cost of production allows plastics to be used in a great variety (Rodriguez, Ferdinand 2022). Plastic waste is most commonly used in household garbage after organic materials; recycling plastic waste is necessary to reduce the risk and find different ways to recycle plastic in an eco-friendly way. Every year, nearly over 300 million tons of plastic waste are discarded, and the amount is increasing at a 9% annual rate. In 2021, Plastics Europe Market Research Group (PEMRG) distribution of total plastic production is showed Fig.1 that Asia accounted for the majority of global plastic production, with a staggering 52% share. Notably, China reached almost one-third of this production figure. Therefore, 75% of all plastic produced has become waste, putting the world's environment and health at serious risk because it needs over 500–1000 years to decompose (seed scientific 2022). **Fig.2** shows the recycling percentage of plastic garbage in relation to each nation's output in 2019. Based on the statistical data, Europe is currently leading as the continent with the highest rate of plastic waste recycling. According to Plastic-fast 2022 report in the year 2020, the management of post-consumer plastics waste in the European Union and three additional countries (EU27+3) saw 35% of the waste being directed towards recycling. (Almeshal, I., Tayeh, B.A., Alyousef, R., Alabduljabbar, H., Mohamed, A.M. and Alaskar, A.,).

Also, Plastic-fast 2022 reported that in the European Union (EU27+3) in 2021, approximately 35% of post-consumer plastics waste was recycled, 23% was disposed of in landfill areas, and 42% was used for renewable energy generation. Incorporating recycled plastic aggregate into concrete is a practical and compelling solution to preserve natural resources and safeguard the environment, considering that aggregates account for nearly 70% of the volume of concrete. This approach offers an intriguing method to minimize the use of conventional aggregates and promote sustainability in construction, contributing to resource conservation and environmental protection. While We take the stones from quarries then crush them to produce the majority of the aggregates. Crushing introduces dust particles into the environment, just as stone quarrying changes the local geology. The fact that these waste products aid in improving the quality of concrete is another benefit of using them. Using recycled plastic aggregate serves a dual purpose: it reduces the use of raw materials in concrete while also utilizing waste materials that are harmful to the environment (Khajuria, A., & Sharma, P. (2019)). Also, recent studies have shown that the use of polymers in the production of concrete, either as an alternative to aggregate or as part of the binder, has the potential to produce structures that perform well in terms of thermal insulation. Liguori, B., & Iucolano, F. (2014).



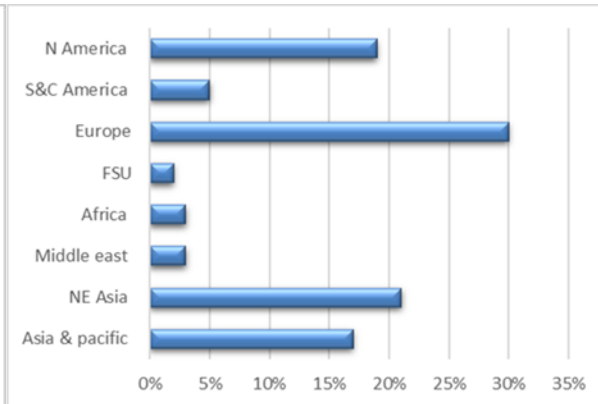


Fig. 1 . Distribution of the global plastic

Fig. 2. recycling production world shared by region.

1.2 Self-compacting mortar

Self-compacting mortar (SCM) is an elementary part of self-compacting concrete (SCC) and is principally used in structural fixing, restoration, and repair of structures, grouting, and producing light-conductivity concrete. While rapid growth in construction work, complicated architecture plans, and structure detailing make working with concrete difficult, it requires a large workforce until it is cast in place. Since self-compacting concrete (SCC) can flow through the formwork without any mechanical vibration, it could be used in precast and cast-in-place projects. SCC workability helps the concrete get a smooth surface easily without bleeding and eliminates segregation, and it's the most helpful material when we have crowded details that could encapsulate the reinforcement more easily. (ACI *237R-07* (2007)). SCC was a critical solution demonstrated at the University of Tokyo by Ozawa and Maekawa in 1988. Before this development, Japan had an essential problem with the durability of concrete structures. Normal concrete needs compaction by skilled workers to be durable and of good quality, and it was hard to control this quality on the site until, in 1986, Okamura proposed the necessity of the concrete being able to easily be molded into different shapes and be more durable (Okamura, H., & Ouchi, M. (2003)). SCC mix is composed of normal concrete mix components: coarse aggregates that form the largest proportion of the mix; fine aggregates such as sand that act as filler material in the voids; binding material such as lime or Portland cement that binds these materials together; and water that reacts with the binding material and viscosity modifying admixture (VMA) that improves the flowability and cohesiveness of concrete like superplasticizer (SP) is also used to reduce yield stress and improve SCM or SCM segregation resistance. This admixture prevents global issues caused by a rising W/C ratio from easily flowing during compaction, which is undesirable because it reduces the strength of the concrete (Okamura, H., & Ozawa, K. (1996); (Khayat, K. H., & Guizani, Z. (1997)). The fundamental engineering characteristics of fresh SCM are mostly what determine the workability of fresh SCC. In actuality, the SCC design was created after a long process of trial and error. However, SCM design takes considerably less time and money and makes it easier to reach a desired SCC. Therefore, it is important to research and balance SCM to reduce SCC phase trials. Generally speaking, SCC or SCM needs more cement than regular concrete to self-consolidate. (Tuaum, A., Shitote, S., & Oyawa, W. (2018).

1.3 Admixture: Silica fume

SCM with recycled plastic aggregate an important way of enhancing the environmental performance of concrete is to use recycled plastic particles in its production. This kind of concrete makes use of waste that would otherwise be stored in landfills. These varieties' primary disadvantage is that their strength is typically lesser. In contrast to conventional concrete, recycled aggregate concrete has lower strengths, higher drying shrinkage and creep, and lower resistance to chloride ion penetration, as demonstrated by prior research studies. (Mirza, F. A., & Saif, M. A. (2010, June) Nowadays, the use of supplementary cementitious materials (SCMs) such as silica fume (SF), fly ash (FA), and ground granulated blast furnace slag (GGBFS) has been very effective in improving the mechanical properties and durability of concrete made with recycled concrete aggregates (RCA) (Sasanipour, H., & Aslani, F. (2019)). Since in this study silica fume is used for incorporation into SCC, it is effective for increasing compressive strength, bond strength with the steel reinforcement, and abrasion resistance. Also, incorporation of silica fume in SCC has an adverse effect on workability, and a higher percentage of superplasticizer is needed for a higher percentage of cement replacement by silica fume. (Pradhan, D., & Dutta, D. (2013)).

1.4 Research objective

The main objectives of this research study are:

- Investigate experimentally the effect of recycled plastic aggregate on the fresh properties of self-compacting mortar.
- According to this study, the mechanical properties, unit weight, and air content of the SCM incorporate recycled plastic aggregate in the following proportions: 5%, 10%, 15%, and 20%, respectively.
- In addition, the properties of the same ratio of recycled plastic aggregate with 10% silica fume are compared to other mixes.

2. Experimental program

2.1 Materials

The influence of RPA and silica fume was studied on self-compacting mortar mixtures of Portland cement, sand, water, and a superplastic sizer. Therefore, to introduce eco-friendly practices, RPA is incorporated as a partial incorporation with fine aggregates (sand) in the mortar mixture.

2.1.1 High-Range Water Reducing Admixture

During this investigation, a commercially available superplasticizer called Hyperplastic PC900 was utilized. This particular superplasticizer ***Fig.3***, obtained from a DCP company, possessed a slump retention capacity. It adhered to the ASTM C494, TYPE G specifications and had a specific gravity of 1.12 g/cm3. The pH value of the superplasticizer fell within the range of 5 to 7. The manufacturer's recommendation for the dosage of this superplasticizer was between 0.5 to 3.5 liters per 100 kg of cementitious materials. However, for this

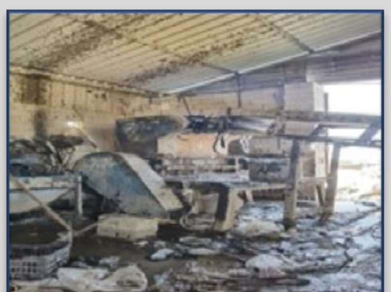
study, the optimum percentage of superplasticizer was determined based on trial mixes conducted during the research.

Fig. 3. Liquid superplastic size

2.1.2 Recycled plastic aggregate (RPA)

The process of recycling plastic had been done at a local factory situated in Halabja, Kurdistan Region, Iraq. The RPA is used as a substitute for conventional fine aggregates (such as sand) that were derived from plastic waste materials. Recycling plastic waste to aggregate particles as shown in ***Fig.5***, is containing collecting process is involves systematically gathering plastic waste from the waste generated by households, businesses, and institutions within a community. This is a difficult process for Halabja Factory because most plastics collect after they enter the municipal waste stream, in some countries people are conscious to collect plastic waste before they enter the municipal. After the crushing and cleaning process the factory is use thermal reprocessing involves subjecting a thermoplastic material to high temperatures, causing it to melt and become fluid. As the plastic cools down, it solidifies into a granular particle less than 4.75 mm in size without undergoing any chemical composition modifications ***Fig.4***. The RPAs obtained for this investigation have a characteristic black color after going through the transformation process. And a specific gravity of 0.9 g/cm3 characterizes these RPAs. The RPAs have circular shapes and smooth surfaces, and their particle sizes range from 1.18 mm to 4.75 mm. These RPAs also show very little water absorption.

Fig. 4. Recycled plastic aggregate size (1.18- 4.75).

		
Collection process	Crushing plastic waste to pellet particle	Washing and cleaning pellet particle
		

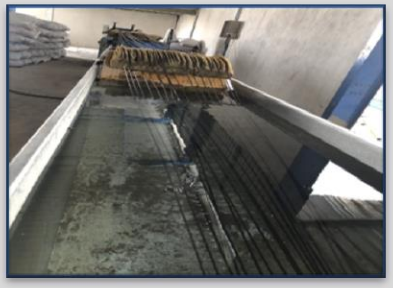
Drying and collecting pellets	Preheating pellets	Melting plastic in a furnace
		
Extruding the melted plastic though the chamber	Cooling the noodle shape plastic in water	Cutting the noodle shape to granular particle

Fig. 5. Process of Recycling plastic waste in Halabja..

2.1.3 Fine Aggregate

In this study, the fine aggregate used was river sand sourced from the Qaladize district in the Kurdistan region. The properties of the river sand were determined in the saturated surface dry (SSD) condition. The water absorption of the sand was found to be 1.37%, indicating its ability to retain moisture. The specific gravity of the sand was measured at 2.77, representing its relative density compared to water. The gradation and sieve analysis of the natural fine aggregate (NFA) were conducted according to the ASTM C33 standard ***Fig.6***.

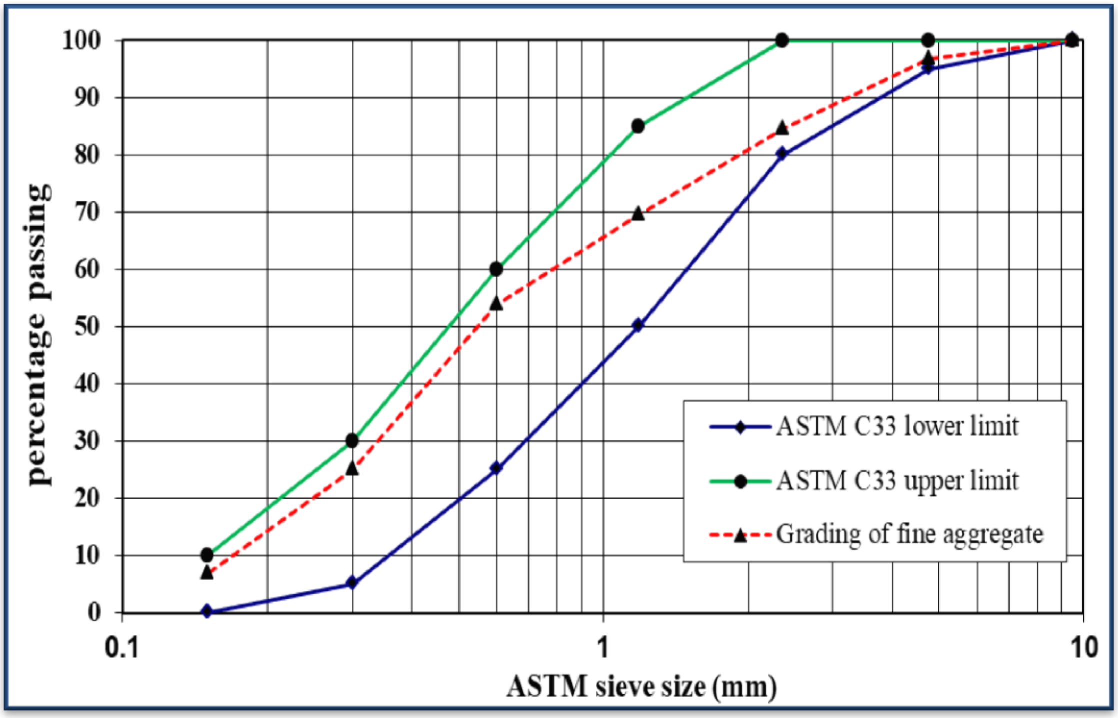


Fig. 6. Sieve analysis of fine aggregate according to ASTM C33.

2.1.4 Water

The water that used in this experiment is totally clean and at room temperature stored.

2.1.5 Cement

For the production of all concrete mixes in this study, Ordinary Portland cement (OPC) CEM I 42.5. The specific brand used was Hawlati, which is commercially available from the Tasluja company located in the Kurdistan region of Iraq. The phisical and chemecal property is shown in *table.1* and *table.2*.

Table. 1. Physical property of ordinary Portland cement

Physical properties	Test result	IQS No.5/2019 limits for OPC
Initial setting time (min.)	125	≥ 45
Final setting time (min.)	205	≤ 600
Blaine fineness (m^2/kg)	306.5	≥ 230
Expansion (mm)	1	≤ 10
Compressive strength(MPa) (2 days)	36	≥ 20
Compressive strength(MPa) (28 days)	49.8	≥ 42.5

Table. 1 physical property of Ordinary Portland cement.

Table. 2. Chemical properties and Oxide compositions of Ordinary Portland cement

Chemical properties and Oxide compositions	**Test results**	**IQS No.5/2019 limits for OPC**
Calcium Oxide (CaO)	61.23	-
Silicon Dioxide (SiO_2)	19.17	-
Aluminum Oxide (Al_2O_3)	4.65	-
Ferric Oxide (Fe_2O_3)	3.2	-
Magnesium Oxide (MgO)	2.62	$\leq$ 5%
Sulpher tri Oxide (SO_3)	2.78	$\leq$ 2.8% For C_3A > 3.5%
Loss on ignition (L.O.I)	3.6	$\leq$ 4%
In Soluble residue (I.R.)	0.32	$\leq$ 1.5%
Main Compounds (Bogue's equation)		
Tri calcium silicate (C_3S)	59.91	-
Tri calcium silicate (C_2S)	10.02	-
Tri calcium aluminate (C_3A)	6.90	-
Tetra calcium alumino ferrite (C_4AF)	9.73	-

2.1.6 Silica fume

In the mixes that used Silica fume which is cementation material with nano particle size fit the pore in the mortar mix. the physical and chemical property is shown in Table.3.

Table. 3 Chemical compositions and physical properties of silica fume.

Oxide (wt.%)	**Result**
CaO	0.143
SiO_2	92.4
Al_2O_3	-
Fe_2O_3	0.129
MgO	0.326
SO_3	0.50
Loss on ignition	7
Specific gravity(g/cm^3)	2.25
Bulk Density (kg/m^3)	650

2.2 Mix proportions.

Generally self-compacting mortar mixtures were designed based on $1m^3$ of total volume that according to a previous study the cement is measured as $700kg/m^3$. Then superplasticizers indicate a 1.4% of cement ratio, and 2% of Air with a W/C ratio equal to 0.3. After the control mix is designed, each additional modification in the mix material should be indicated in according to the control mix as Tabile.4 showed. In this study, the proportion of RPA is the main factor of pattern, that according to RPA the cement system structure is divided into two stages with and without silica fume. These stages of the mix are making formation in the modifying admixtures presence and determining their optimal dosages in the organometallic modifier composition. The first stage is modifying the control mix design by incorporating RPA in addition to sand at four ratios the cement and superplasticizer ratio remains as the control mix. The second stage starts after replacing the cement with 10% of silica fume (SiO2) this Nano particle is cause to change total cementation system to dryer though it fills the pore ***Fig.6***, evaluate silica fume particle with cement particle. Therefore, the superplasticizer ratio increased to 2% of the control mix cement ratio. Totally 10 mixes are designed were half of them modified with 10% of silica fume and in 8 mixes fine aggregate replaced with RPA by weight at the varying percentages of (5%, 10%, 15%, and 20%) as shown in *Table.4.*

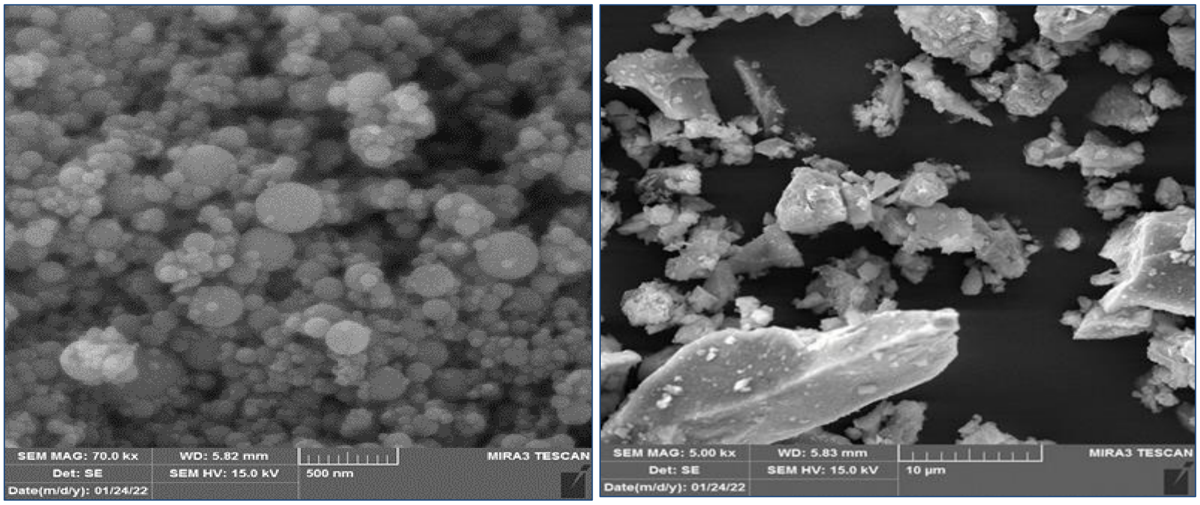


Fig. 6. evaluating silica fume particle size to cement particle size in SEM image

Table. 4. **S**elf-compacting mortar incorporating recycled Plastic aggregate mix proportioning.

MIX Designation	W/C	cement (kg/m3)	water (kg/m3)	sand (kg/m3)	super plastic sizer (kg/m3)	RPA (kg/m3)	silica fume (kg/m3)
C	0.35	700.00	245.00	1394.51	10.00	-	-
5% P	0.35	700.00	245.00	1324.78	10.00	22.65	-
10% P	0.35	700.00	245.00	1255.06	10.00	45.31	-
15% P	0.35	700.00	245.00	1185.33	10.00	67.96	-
20% P	0.35	700.00	245.00	1115.61	10.00	90.62	-
SF	0.35	630.00	220.50	1454.68	14.00	-	70.00
5%SP	0.35	630.00	220.50	1426.98	14.00	9.00	70.00
10%SP	0.35	630.00	220.50	1399.28	14.00	18.00	70.00
15%SP	0.35	630.00	220.50	1371.58	14.00	27.00	70.00
20%SP	0.35	630.00	220.50	1343.88	14.00	36.00	70.00

2.3 Test methods

2.3.1 Preparation and sample conditioning

For this study, the prismatic 40 × 40 × 160 mm³ sample and cubic 50 × 50 × 50 mm³ sample were used as shown in ***Fig.7***, and 24 hours after casting they were stored in water. To examine the properties of the samples, a range of tests and measurements were conducted. These tests aimed to investigate both the physical and mechanical characteristics of the samples. The physical properties that were studied included porosity and water absorption. On the other hand, the mechanical properties analyzed were flexural and compression. By performing these tests and measurements, a comprehensive understanding of the physical and mechanical properties of the samples could be obtained.

Fig. 7. casted sample before hardening

2.3.2 Physical property

The workability of the control mix evaluated after mixing the material in the mixer, that by slump test optimum w/c ratio is indicate as 0.35. The workability of mortar mixtures was estimated by the flow spread diameter of cement-sand mortars as showed in ***Fig.8***.

Fig. 8. Slump test of the control mix.

The porosity was determined by the knowledge of the saturated and oven-dried mass of samples. Three cubic samples (50×50×50 mm3) were tested at 28 days. The dried mass was obtained after drying saturated in an oven at 60 °C until constant weight. The water absorption test was carried out on the same samples which were served for the determination of porosity according to ASTM C642. The oven-dried dry mass of each sample was recorded and then they were totally immersed in water until they achieved a constant mass. The constant mass was taken as the saturated mass of the sample after 48 h. The absorption percentage was then obtained by the ratio of the amount of water absorbed to oven-dried mass.

2.3.3 Mechanical property

Three-point flexural strength and uniaxial comparison test are in 28 days experienced according to ASTM (C78-C293). During three-point description is a test that involves supporting the sample prism 40 × 40 × 160 mm^3 at two points on opposite ends, while a third point is applied bending stress as a deflection in the center of the length (160mm). For each mix, three prisms were tested and brought down the point and the SCM prism deflect until arrive at its rapture strength ***Fig.10***. Also, in the compression test cubic sample (50×50×50 mm3) is positioned between two plates, which evenly distribute the applied load across the entire surface area of the sample's opposite faces. Three cubes were tested for each mix that was subjected to a uniaxial compression force until the cube was crushed at its ultimate strength as shown in ***Fig.9***

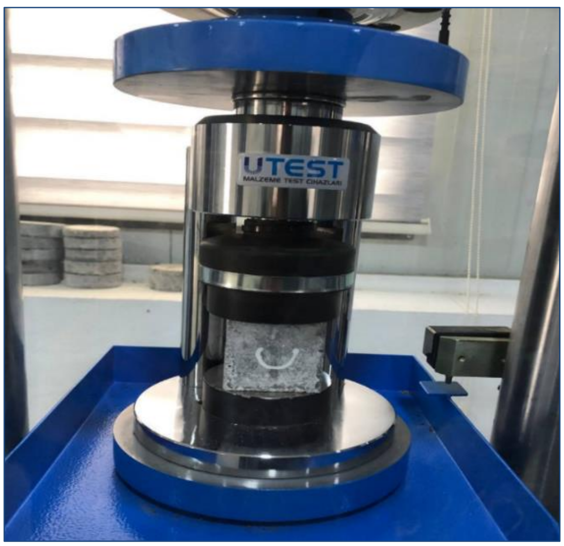


Fig. 9. Compression test

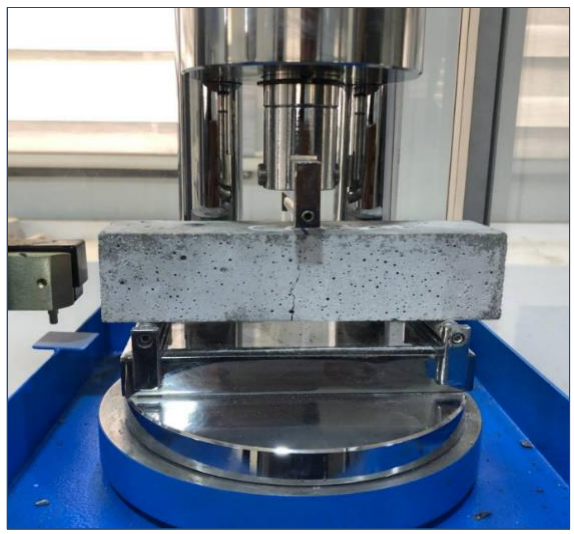


Fig. 10. Three point flextural test.

3. Evalution of results

3.1 Discussion of results

Here we discuss our results and the effects of used materials in our research. We had 3 tests to conclude the effects and show their adverse impact. The tests were compression strength, flexural strength and water absorption test.

3.2 Compression strength

As we previously mentioned the size of the cubes used for the compression strength test were 5*5*5 cm. For each test we used 3 samples and took the average, thus making the total number of samples for this test 30 samples. And

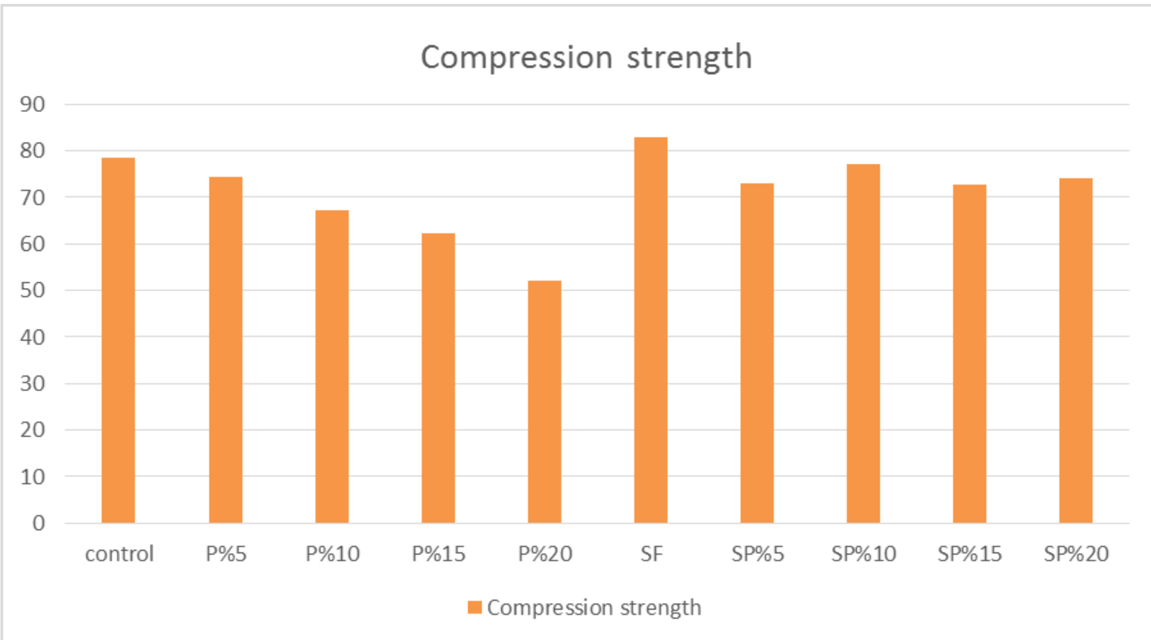


Fig. 11. The average compression strength.

here are the averages as shown ***Fig.11***. We can clearly see the compression strength decreasing with the increase of plastic composition. In one of the research's, it is mentioned "the utilization of plastic bags and seats results in a deterioration of compressive strength while concurrently enhancing tensile strength. However, the implementation of PVC in concrete leads to an escalation of both types in tensile strength. Notably, the implementation of a 10% replacement level merely exhibited a 15% reduction in compressive strength after 28 days in comparison to the control" (Sangal, G.S. (2018). Study the effect of plastic waste on strength of concrete. *International Journal for Advance Research and Development, 3,* 36-39.). However, the rate of decrease in strength is from 5 to 9 % but the rate of decrease between %15 plastic to 20% plastic jumps to 16% and this can be explained by previous research which stated "A substitution of 15% of natural aggregate with plastic aggregate results in the highest compressive strength of concrete after a period of 28 days, when compared to varying proportions of plastic replacement." (Tamang, T., Wangmo, T., Darjay, K.T., Phuntsho, K., Namgyal, P., & Wangchuk, U. (2017). Use of Plastics in Concrete as Coarse Aggregate.) the jump that happened in the decrease shows that mortar of the %15 plastic replacement gained strength faster than the other ones as it should normally have been lower in strength. To compensate for the loss in strength we used silica fume as silica fume can "improve the interface bond strength between hardened cement paste and aggregate and thus compensating or even further enhancing the strength" (Zhang, Z., Zhang, B., & Yan, P. (2016). Comparative study of effect of raw and densified silica fume in the paste, mortar and concrete. *Construction and Building Materials, 105,* 82-93.). The strength decreased with increasing plastic percentage however with silica fume it's a different case. With silica fume the numbers fluctuate and are not what you would normally expect. The reason for this is that we used same amount of materials for our mixes but silica fume causes "A reduction in workability, as measured by slump value, has been observed with an increase in the percentage replacement of SF. From this, it can be deduced that the optimal percentage of SF replacement lies within the range of 8-10%, specifically for enhancing compressive strength" (Imam, A., Kumar, V., & Srivastava, V. (2018). Review study towards effect of Silica Fume on the fresh and hardened properties of concrete.). And this results in dampening the distribution of plastic aggregates. We used a very small amount of super plasticizer to increase workability because "Superplasticizers are considered as admixtures which are deliberately incorporated into the concrete blend in small quantities" (Papayianni, I., Tsohos, G.H., Oikonomou, N., & Mavria, P. (2005). Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures. *Cement & Concrete*

Composites, *27*, 217-222.) and “The utilization of superplasticizer facilitated a noteworthy decrease in the amount of water required while simultaneously retaining the same level of workability” (Singh, S.P., & Chaitanya, I.K. (2014). INFLUENCE OF SUPERPLASTISIZER ON FLOW AND STRENGTH CHARACTERISTICS OF CONCRETE.). The reason we used up to %20 replacement of aggregate is because “The act of substituting cement with recycled brick powder containing a higher content of 20% has been found to result in a decrease in the workability of self-compacting mortar by approximately 3%” (Irki, I., Debieb, F., Ouzadid, S., Dilmi, H.L., Settari, C., & Boukhelkhel, D. (2018). Effect of Blaine fineness of recycling brick powder replacing cementitious materials in self-compacting mortar. *Journal of Adhesion Science and Technology*, *32*, 963 - 975.), Thus the percentage of aggregate replacement should be considered for self-compacting concrete.

Fig. 2. The average compression strength.

3.3 Flexure strength test

The samples we used for this test were prisms with dimensions 4*4*16 cm. The following were the test results. The number of samples we used for the test was same as the compressive test 3 for each and total of 30 samples. The following **Fig.12.**

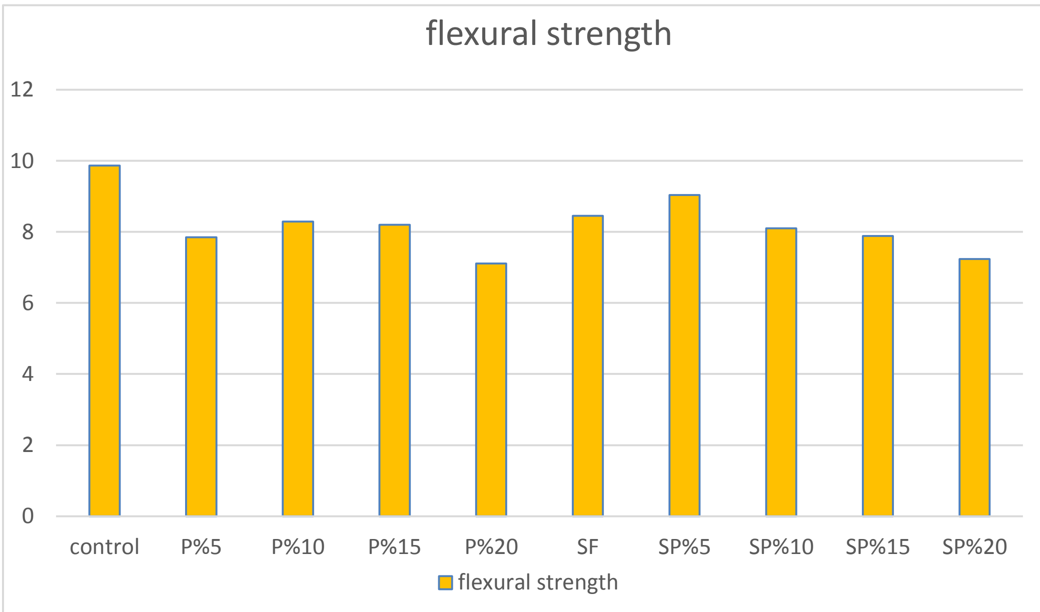


Fig. 12. The average flexural strength

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nlike the compression strength results the flexure test results are unpredictable in both mixes. Whether the mix has silica fume or not the result was not within expectation and there isn't a certain pattern. The reason for this is probably related the type of the plastic aggregate as the plastic aggregate is recycled plastic waste it comes from various sources. Because in another research "The utilization of a plastic bag and seat in concrete results in a reduction in compressive strength, while displaying an increase in tensile strength. However, the use of PVC in concrete yields better results in tensile strength for both materials. Despite its inferior performance in compression, the tensile strength experiment demonstrated that the specimens with 10%, 20%, and 30% replacements exhibited superior tensile strength in comparison to the control" (Sangal, G.S. (2018). Study the effect of plastic waste on strength of concrete. *International Journal for Advance Research and Development, 3,* 36-39.). And this shows the type of the plastic aggregate clearly plays a big part in flexural strength because their chemical composition is different their elasticity will also be different. However, if we were to use plastic fiber instead of aggregates it would increase flexural strength as it is mentioned "The inclusion of discarded plastic fibers has been found to result in a reduction of compressive strength, while concurrently increasing the flexural tensile strength" (Mouats, W., Abdelouahed, A., Hebhoub, H., & Boughamsa, W. (2021). The Effect of Plastic Waste Fibers on Mortar Performance. *Architecture, Civil Engineering, Environment, 14*, 95 - 103.) and this goes to show the shape of the aggregate plays a big part in flexural strength.

3.4 Water absorption test

For this test we used three cubic samples as compressive strength test. Here are the test results average ratio of the samples as shown in **fig. 13**. The number of

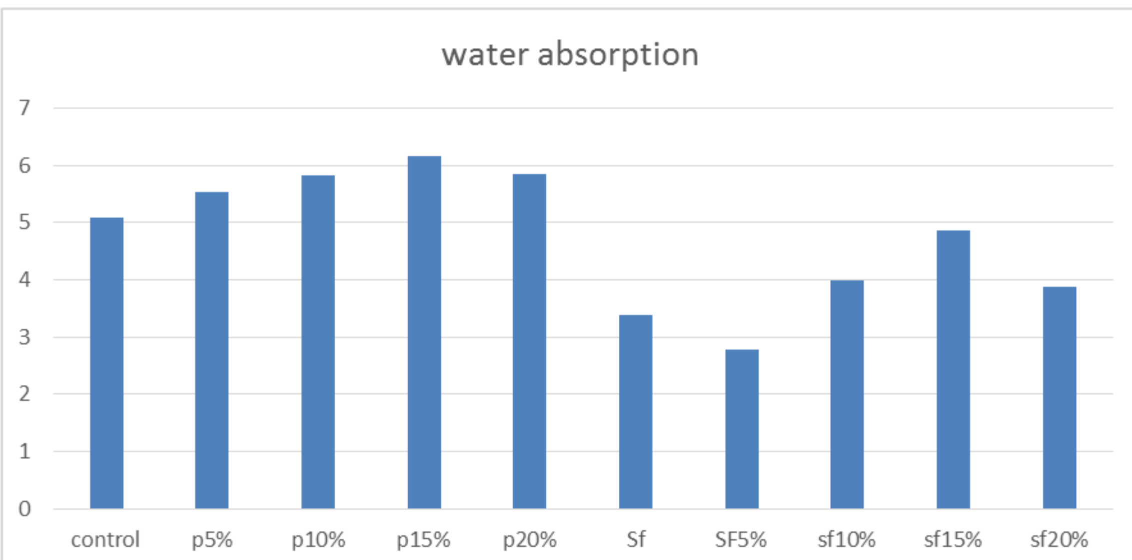

Fig. 13 Water absorption ratio.

samples used for this test is same as previous test which is a total of 30 samples.

The first thing that is noticeable is that the numbers have decreased greatly with the incorporation of silica fume into the mix. It is shown that "silica fume has the ability to reduce water absorption and reduce the number of pores" (Sasanipour, H., Aslani, F., & Taherinezhad, J. (2019). Effect of silica fume on durability of self-compacting concrete made with waste recycled concrete aggregates. *Construction and Building Materials, 227*, 116598.) . also "silica fume reduces permeability" (Rostami, M., & Behfarnia, K. (2017). The effect of silica fume on durability of alkali activated slag concrete. *Construction and Building Materials, 134*, 262-268.) . We can also see normally without silica fume the water absorption increases up to a certain point of plastic aggregate percentage. It was stated "The application of waste plastic aggregates yielded a decrease in the density of concrete, while concurrently increasing its permeability and water absorption rates. Furthermore, this practice led to a reduction in the strength of the concrete." (Mohammadhosseini, H., Alyousef, R., & Md. Tahir, M. (2021). Towards Sustainable Concrete Composites through Waste Valorisation of Plastic Food Trays as Low-Cost Fibrous Materials. *Sustainability*.) and "The incorporation of this particular element serves to enhance the water absorption of fresh mortar, while simultaneously decreasing the bulk density of cured mortar." (Roopa, M., Das, S., Sanjana, M., & Thungashree, B.S. (2022). Study On Partial Replacement Of E-Plastic Waste As Coarse Aggregates. *Journal of Mines, Metals and Fuels*.) also "Although there are certain limitations associated with it, such as a decline in the compressive strength and fire resistance, the utilization of waste PET aggregates offers several benefits. These include a decrease in density and water absorption as well as an increased frost resistance of the cement mortar." (Yilmaz, A. (2021). MECHANICAL AND DURABILITY PROPERTIES OF CEMENT MORTAR CONTAINING WASTE PET AGGREGATE AND NATURAL ZEOLITE. *Ceramics - Silikaty*.) , another one states "The incorporation of plastic aggregate results in a noteworthy enhancement of thermal insulation and evinces a superior resilience to capillary water absorption in contrast to the reference sample." (Cardinale, T., Sposato, C., Alba, M.B., Feo, A., & Fazio, P.D. (2019). Energy Performance of Construction Materials Using Waste Recycled Polymer as Fine Aggregate Replacement. *International Journal of Heat and Technology*.) . The aforementioned research papers have different results when it comes to water absorption if waste plastic is used as aggregate, some of them state that it increases water absorption while some of the others say it decreases water absorption and this concludes that different materials as well as the shape of the material determines water absorption decrease or increase. As for our research it clearly shows with increase of plastic aggregate water absorption increases to a certain point which was %15 percent as this was the result in both cases with and without silica fume. And this is clearly due to the plastic aggregate making changes in the infrastructure and increasing pores. This result also supports the rate jump in the compression strength section as the number drastically changes %15 plastic to %20 plastic.

4. Conclutions

4.1 Compressive strength

From the compressive strength test we found out with increase of plastic percentage the compressive strength decreases however the rate of decrease still needs further research as %15 plastic percentage shows that it gained strength slightly faster, meaning its hydration process happened faster than the other percentages. Also using silica fume will decrease the workability of the mix and thus percentage of the silica fume should be considered when used in the mix.

4.2 Flexural strength

The results for this test didn’t show a certain pattern. The reason for this is the type of plastic and most likely the shape, as strands such as fibers will probably give better flexural strength with increase of plastic percentage. But in our case, we used aggregates.

4.3 Water absorption

From this test we concluded that with the incorporation of silica fume water absorption decreased because it decreases the number of pores and so reducing permeability too. Aside from the silica fume generally we also saw that with increasing the percentage increases water absorption to a certain percentage which was %15 and at %20 it decreased. This is because with increasing the plastic percentage we also increased number of pores in the mortar. As for the difference between the %15 and %20 it is because of the faster hydration in the %15.

4.4 Recommendation for further research

The effects of plastic beyond %20 still seem uncertain. It is advised that higher plastic percentages should be used to research in the same area.

It is also advised the starting percentage to be used be at least %15, because we discussed the importance of this percentage but further research should also be done on this.

Use other materials or modify the mix in a way to increase workability when using silica fume but also not increasing cost and keeping balance.

If possible, try to use other shapes for the aggregate. An elongated or more flat shapes would be preferable this could return some of the lost compressive strength, because of better bond, and increase flexural strength.

Some other tests to be done for example: chemical resistance, electrical conductivity.

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