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Comparing The Abrasion Resistance of Conventional Concrete and Green Concrete Samples

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Abstract

Significant volumes of non-biodegradable solid waste are related to industrial activity in Iraq, with waste plastic being one of the most notable. 24 samples were used in this study to test the effectiveness of recycling waste plastic to make concrete. Four different ratios of waste plastic from both green and conventional concrete were used as a partial replacement for gravel: 0%, 30%, 60%, and 100%. All of the concrete combinations were tested at room temperature. These tests include compressive strength and abrasion resistance. The compressive strength was determined by molding 36 cubes. In this study, concrete mixes were cured for 3, 7, and 28 days. The apparatus created in the Construction Laboratory of the Civil Engineering department at Wasit University was used to measure the rate of concrete erosion by directing a high-velocity jet of a water and sand combination at concrete samples. A determination was also made on the impact of the impingement angle. Using two distinct angles (45 and 90) with the horizon, experimental estimations were performed. The results of the experimental studies showed that the flow inclination angle of 45 with the horizon can achieve the highest rate of erosion, while the flow inclination angle of 90 with the horizon can achieve the lowest rate. Additionally, the results showed that erosion decreased as the plastic percentage increased with age. The compressive strength of mixtures containing 0%, 30%, 60%, and 100% plastic particles was tested using 10-cm cube specimens. Compressive strength was reduced due to the use of plastic granules. This study confirms that recycling waste plastic as a gravel substitute in concrete offers a promising solution to lower material costs and address some of the issues with solid waste that plastic presents.

Keywords: Hydraulic structures, Flow inclination angle, Erosion, Abrasion, Green Concrete, Plastic waste.

الخلاصة: ترتبط كميات كبيرة من النفايات الصلبة غير القابلة للتحلل بالنشاط الصناعي في العراق ، وتعتبر نفايات البلاستيك واحدة من أبرزها. تم استخدام 24 عينة في هذه الدراسة لاختبار فاعلية إعادة تدوير مخلفات البلاستيك لصنع الخرسانة. تم استخدام أربع نسب مختلفة من نفايات البلاستيك من كل من الخرسانة الخضراء والتقليدية كبديل جزئي للحصى: 0٪ ، 30٪ ، 60٪ ، 100٪. تم اختبار جميع التركيبات الخرسانية في درجة حرارة الغرفة. تشمل هذه الاختبارات قوة الانضغاط ومقاومة التآكل. تم تحديد مقاومة الانضغاط من خلال صب 36 مكعبًا. في هذه الدراسة ، تمت معالجة الخلطات الخرسانية لمدة 3 و 7 و 28 يومًا. تم استخدام الجهاز الذي تم إنشاؤه في معمل البناء التابع لقسم الهندسة المدنية في جامعة واسط لقياس معدل تآكل الخرسانة عن طريق توجيه نفاثة عالية السرعة من مزيج الماء والرمل في عينات الخرسانة. كما تم تحديد تأثير زاوية الاصطدام. باستخدام زاويتين مختلفتين (45 و 90) مع الأفق ، تم إجراء تقديرات تجريبية. أظهرت نتائج الدراسات التجريبية أن زاوية ميل التدفق 45 مع الأفق يمكن أن تحقق أعلى معدل تآكل ، بينما زاوية ميل التدفق 90 مع الأفق يمكن أن تحقق أقل معدل. بالإضافة إلى ذلك ، أظهرت النتائج انخفاض التعرية مع زيادة نسبة اللدائن مع تقدم العمر. تؤكد هذه الدراسة أن إعادة تدوير نفايات البلاستيك كبديل للحصى في الخرسانة يقدم حلاً واعدًا لخفض تكاليف المواد ومعالجة بعض المشكلات المتعلقة بالنفايات الصلبة التي يمثلها البلاستيك.

1. Introduction

Due to the swift expansion of the world economy, demand for the many industrial materials needed for everyday necessities has expanded dramatically. This manufacturing-related development has two detrimental effects on the environment. First, the expansion of the manufacturing sector raises energy consumption, which in turn raises carbon dioxide emissions. For instance, the manufacture and transportation of plastic resin results in the release of around 2.5 tons of CO_2 into the environment per ton. Second, the materials created are generally utilized for a brief period, partially used, or discarded. As a result, the wastes from these materials require treatment and disposal, which has an influence on the ecology of the treatment zone (soil, water, and air) [1]. Plastic recycling is a potential solution. Plastic has a high calorific value and may be burned or utilized in other high temperature operations since it is made of organic hydrocarbons. However, burning plastics causes a number of harmful compounds, including dioxins, one of the most dangerous substances, to be released into the air. After processing, plastic trash may potentially be utilized to create new plastic-based goods. However, the procedure is not cost-effective because the recycled plastic loses its quality and must be replaced to create the original product [2]. The considerable growth in the usage of concrete in recent years, estimated at over 30 billion metric tons per year worldwide, is offset by a scarcity of raw resources on our land [3]. The massive number of natural resources that the concrete industry uses has a direct influence on energy use, economic impact, and the massive build-up of industrial waste. As a result, there are two issues. The first is a lack of resources, specifically raw materials, for making concrete. The second point to consider is how these plastic wastes are disposed of. Consequently, the concept of recycling old concrete to create new concrete was quite successful in various nations. To address the practical and technological issues related to the reuse of plastic waste in concrete, researchers have been experimenting and continue to apply the most promising technologies [4]. With a population of more than 39 million people, Iraq imports a considerable quantity of varied fruits and vegetables packaged in plastic. All of these used plastic crates are disposed of in landfills. Decomposition takes years, which increases the risk to the ecosystem in Iraq and causes problems for the environment [5].

2. Experimental work

2.1. Test procedure and studied samples

Concrete abrasion resistance was measured using custom-built water jet testing equipment in the hydraulics lab at Engineering College/Wasit University. The workings of the tool used are depicted in Fig. 1. The abrasion test object was a plate that measured exactly 200mm in width, 200mm in depth, and 50mm in thickness. The sample was held at a distance of 20 cm [6] from the jet using the device's specimen holder, which can be adjusted to accommodate both of the applied flow inclination angles (45 and 90). Water jet flow testing, the most popular type of abrasion testing, was used to measure the concrete's abrasion resistance in relation to the water flow's impact at different angles and the particles carried by the water. Liu et al 2006. of Taiwan were the first to propose this method. Several research projects [6] [7] [14]. Were created abrasion by rubbing together sand and water. The resulting concoction simulates the effect that abrasive materials have on real-world hydraulic systems. Sand with particles measuring 0.6 mm in size was mixed with water. The final combination contained 30 kg of sand per cubic meter. The water tank's foundation measured 2.0 m by 0.75 m, while the tank itself stood 1.5 m tall. The tank was filled with 1 m3 of water. To ensure that the water and sand were well mixed, two electric mixers were installed within the tank. A centrifugal pump coupled to an intake pipe was used to collect the mixed water. The mixture was poured directly onto the concrete plate at a speed of 10 meters per second using a rectangular nozzle of 200 millimeters by 10 millimeters, as shown in Fig. 2. The duration of the examination was three hours. This study employed 24 samples to examine the viability of using recycled plastic in concrete. Gravel was mixed with either 0%, 30%, 60%, or 100% recycled plastic from eco-friendly and regular concrete. All the concrete mixtures were examined at ambient temperature. To measure the compressive strength, 36 cubes were cast. The curing times of 3, 7, and 28 days were tested with various concrete mixtures. Fig 3. compressive strength test machine.

Fig 1. Water –Jet test Machine

Fig 2. Water-Jet

Fig 3. Compressive strength test machine

2.2. Materials used

2.2.1. Cement

In this research, ordinary Portland cement type R-42.5 was employed. The chemical makeup and physical characteristics of cement are given in Tables 1 and 2. The boundaries of the Iraqi Standard Specification were consistent with test findings (I.Q.S. No. 5, 1984).

Table 1: Chemical composition of cement

Property	% by weight	I.Q.S. No.5, 1984
SiO_2 %	21.04	-
CaO %	63.16	-
MgO %	2.72	5.0 (max)
Fe_2O_3 %	3.46	-
Al_2O_3 %	4.36	-
SO_3 %	2.01	2.8 (max)
Loss on Ignition (LOI)	1.38	4.0 (max)
Insoluble Residue (I.R)	1.09	1.5 (max)
Lime saturation factor (L.S.F)	0.88	0.66-1.02

Table 2: Physical properties of cement

Physical properties	Test results	I.Q.S. No.5, 1984
Specific Surface Area (m^2/kg)	335.4	230 (min)
Setting time Initial setting, min Final setting, hrs	00:55 3:00	00:45 (min) 10:00 (max)
Soundness (Autoclave expansion %)	0.24	0.8 (max)

2.2.2 Coarse Aggregate

The coarse aggregate used in this research, which had a maximum particle size of 10 mm, came from the Badra quarry. According to Table 3, the aggregate's grading complied with the requirements of the Iraqi Standard (IQS No. 45, 1984).

Table 3: Coarse aggregate grading

Sieve Size	Passing %	Limit of Iraqi Specification (IQS) No 45/1984 (10mm)
19.0mm	100%	100
9.5mm	97.48%	85-100
4.75mm	16.24%	0-25
pan	zero	zero

2.2.3. Fine Aggregate

Fine aggregate, silica sand with a grading size of 0.08–0.25 mm and a bulk density of 1.5 kg/L was employed. The sulfate concentration was 0.09%, matching I.Q.S. No. 45, 1984 (0.5). The sieve analysis of this fine sand that met the criteria of the Iraqi Specification (I.Q.S. No. 45, 1984) and Zone 4 is shown in Table 4.

Table 4: Fine aggregate grading

Sieve size	Passing %	Limit of Iraqi Specification (IQS) No 45/1984/ Zone 4
4.75mm	100%	95-100
2.36mm	100%	95-100
1.18mm	100%	90-100
600 μm	100%	80-100
300 μm	42.02%	15-50
150 μm	13.82%	0-15
pan	zero	zero

2.2.4. Recycled plastic aggregate

The recycled plastic coarse aggregate in this work was made from the vegetable plastic boxes shown in Fig 3a. The plastic was first collected and then shredded into tiny pieces, mimicking the coarse aggregate found in the concrete industry. Fig 3b shows the shredding gear used to cut the plastic boxes. Fig 3d shows the pieces of recycled plastic after they have been collected in the proper quantity, washed, air dried, and sieved using standard coarse aggregate sieves. The pieces of recycled plastic were then sorted and packaged according to their particle size, as determined by the sieve analysis performed earlier, as shown in Fig 3e. The plastic parts' colors and shapes were determined by the original box's contents and hue. while the physical properties of the recycled plastic waste aggregate are listed in Table 5.

Table 5. Physical properties of the recycled plastic coarse aggregate

Property	Value	ASTM Standard
Density (kg/m3)	0.949	ASTM D792 (ASTM D792-20, 2020)
Water Absorption	0	ASTM D570 (ASTM D570-98R18, 2018)
Modulus of Elasticity (MPa)	358.7	ASTM D638 (ASTM D638-14, 2014)
Compressive Strength (MPa)	26.4	ASTM D695 (ASTM D695-15, 2015)
Tensile Strength (MPa)	7.7	ASTM D638 (ASTM D638-14, 2014)
Flexural Strength (MPa)	878.3	ASTM D790 (ASTM D790-17, 2017)

Fig 4. Depicts the process by which plastic waste is converted into a coarse aggregate. (A) Vegetable-based plastic packaging. (B) tearing up the plastic shipping containers. (C) Compiling the sliced components. Sorting the trash plastic by size (D). (E) Classifying the fragments of plastic into piles according to their particle sizes.

2.2.5. water

The mixing of the concrete was done with tap water.

2.3. Mix design

Table 6 displays the percentages of mixes containing plastic, where four ratios of plastic trash were utilized as partial replacements for coarse aggregate (by weight of gravel).

Table 6: Proportions of the materials utilized

Material	Quantities (kg/m^3)			
	Mix 1=0%	Mix2=30%	Mix3=60%	Mix4=100%
Cement	420	420	420	420
Sand	819	819	819	819
Gravel	939	657	376	0
Plastic	0	282	563	939
Water	210	210	210	210
w/c *	0.5	0.5	0.5	0.5

*Water to cement ratio

A) casting concrete samples   B) Curing samples

Fig 5. depicts (A) casting concrete samples and (B) curing samples.

3. Results and discussion

This section presents the results of 24 water jet [8] experiments conducted on conventional and green concrete samples. Each sample's abrasion-induced weight loss is expressed as a percentage, or "abrasion weight loss" (AWL), using the following formula.

AWL (%)=100(WP – Wt)/ WP

where wp is the sample weight before testing began and wt is the sample weight after three hours of testing. The AWL for the 3, 7, and 28-day-old testing are shown in Tables 6 and 7. In Fig. 5, we can see how the erosion rate on the surface of each sample changes depending on the inclination angle and plastic ratio. Erosion was most severe when the flow was inclined at 45 degrees to the horizon and least severe when the flow was inclined at 90 degrees to the horizon.

plastic ratio 0%   Plastic ratio 30%

plastic ratio 60% plastic ratio100%

Fig 6. Depicts the effects of various inclination angles and plastic ratios on the rate of erosion at the surface of each sample under study.

Table 7 shows the test results in this study at angle 45 degree.

Mix	Age=3			Age=7			Age=28		
	Weight before	Weight after	Abrasion Weight Loss(AWL)	Weight before	Weight after	Abrasion Weight Loss(AWL)	Weight before	Weight after	Abrasion Weight Loss(AWL)
M1=0%	5.1048	5.0853	0.3819	5.0542	5.50354	0.3719	4.8241	4.8067	0.3606
M2=30%	4.404	4.380	0.5449	4.4243	4.4060	0.4136	4.4431	4.4278	0.3443
M3=60%	3.247	3.2161	0.9516	3.2563	3.2399	0.5036	3.235	3.225	0.309
M4=100%	2.780	2.725	1.9784	2.9692	2.9477	0.7241	2.462	2.455	0.284

Table 8 shows the test results in this study at 90 degrees.

Mix	Age=3			Age=7			Age=28		
	Weight before	Weight after	Abrasion Weight Loss(AWL)	Weight before	Weight after	Abrasion Weight Loss(AWL)	Weight before	Weight after	Abrasion Weight Loss(AWL)
M1=0%	5.0527	5.0377	0.2968	5.1346	5.1213	0.2590	5.2784	5.2651	0.2519
M2=30%	4.310	4.290	0.464	4.3018	4.2858	0.3719	4.0353	4.0253	0.247
M3=60%	3.755	3.725	0.7989	3.441	3.426	0.437	3.353	3.345	0.238
M4=100%	2.2872	2.2453	1.8319	2.4883	2.4753	0.5224	2.2295	2.225	0.201

3.1. Impact on compressive strength

The compressive strength of mixtures containing 0%, 30%, 60%, and 100% plastic particles was tested using 10-cm cube specimens. Table 8. display the mean compressive strength of samples after 3, 7, and 28 days for each combination, illustrating the impact of replacement waste particles. Compressive strength was reduced due to the use of plastic granules. This drop agrees with those seen by Hussain et al. [9], which used different percentages of PBPs (20%, 40%, 60%, and 80%) concentrations and discovered corresponding decreases in compressive strength of 7.37%, 17.68%, 38.6%, and 45.65%. Gopi [10], was used recycled PET bottle particles in increments from 5% to 25% to replace fine aggregate in concrete, confirms these results. Also mentioned that while 5% sand replacement was optimal, 10% closely replicated the control specimens' compressive strength after failure. However, despite numerous fractures on the cube's surface, the specimens that included PBWPs maintained their original shape. In Fig. 7, it can see that the progressive erosion of test specimens with different compressive strengths as the plastic ratio was varied from 0% to 30% to 60% to 100%. Clearly, eroding weight loss was slowed considerably after a boost in compressive strength at age 28. This behavior can be confidently predicted as a result of the enhanced concrete surface and higher compressive strength. This result agrees perfectly with what has been found in the literature [11-13]

Table 9: Compressive strengths of specimens at the ages of 3, 7, and 28 days (MPa)

Age	compressive strength (MPa)			
	Mix1=0%	Mix2=30%	Mix3=60%	Mix4=100%
3	10.4	7.3	5.6	3.5
7	22.4	13.5	12.1	7.4
28	25.6	17.3	15.3	9.6

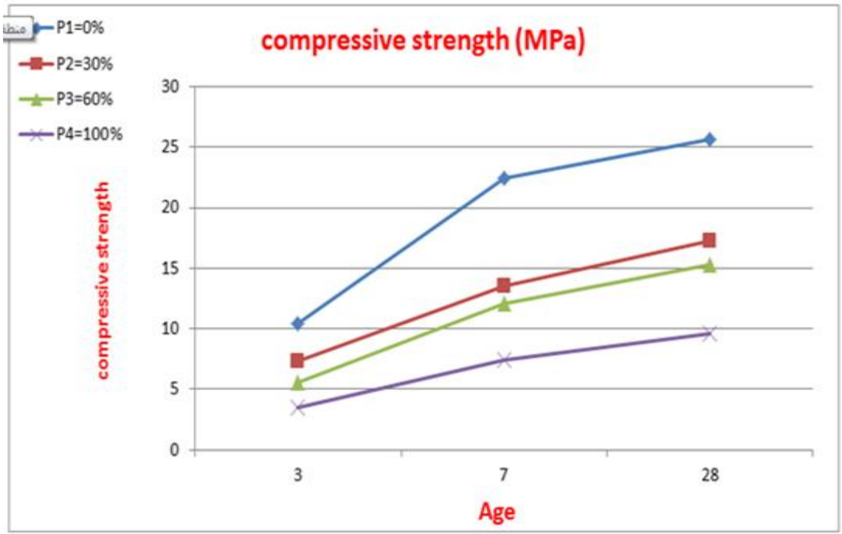
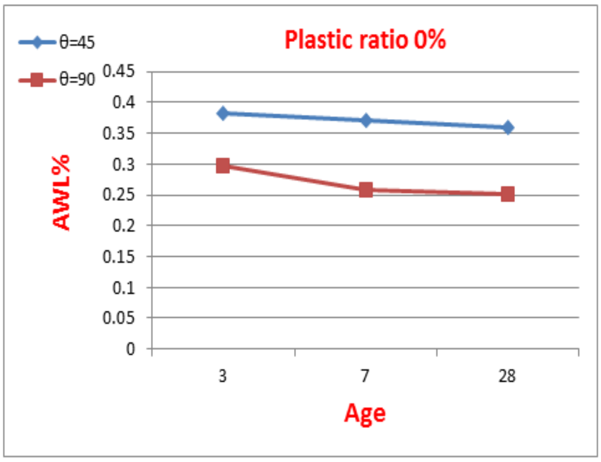


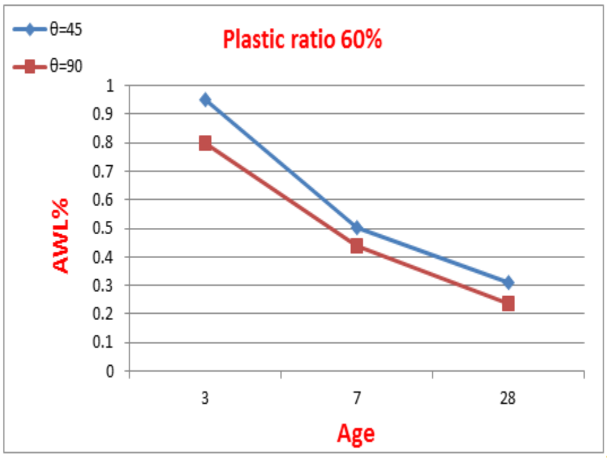
Fig 7. Depicts the compressive strength.

3.2. Impact on the flow inclination angle

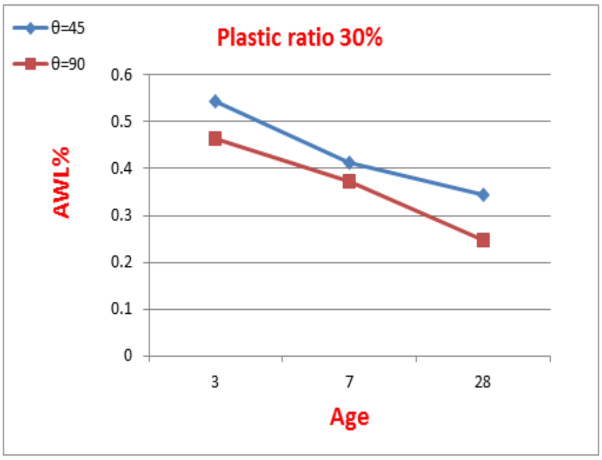
In Fig. 8, the specimens were utilized to demonstrate the influence of the inclination angle. It demonstrates that the specimens' angle of inclination had a direct influence on the erosion. Clearly, a 45-degree flow inclination angle caused the most severe erosion damage. This occurred because, in the case of the perpendicular water flow (90), the water's impact at the surface is what generated all of the pressure. However, when pressure is applied to inclined surfaces, the force is split into two vehicles, with only the normal exerting a significant influence on the surface. This is consistent with the findings of Rawaa H. Ismaeil et al. [13] and [15], which used the horizon and four degrees of flow inclination (0, 30, 45, and 60). For all investigations, the seven-days age of concrete was used. Examples were used to illustrate the result of the inclination angle. It was evidence that the angle of inclination of the specimens had a direct influence on the erosion. At 45, the most significant erosion damage is observed.



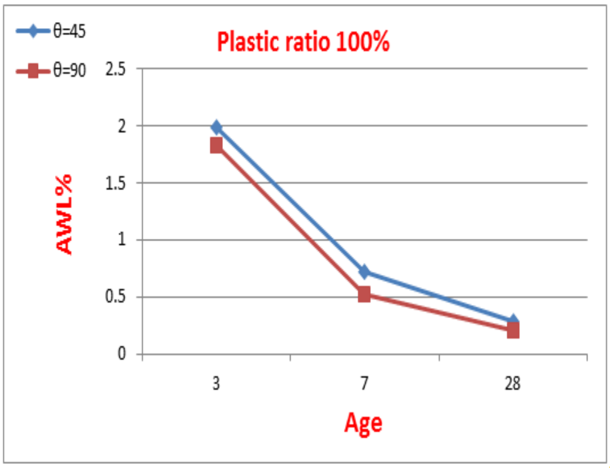
(a)



(c)



(b)



(d)

Fig 8. Shows the abrasion weight loss of two angles, 45 and 90 (a) plastic ratio of 0%, (b)plastic ratio of 30%, (c)plastic ratio of 60%, (d)plastic ratio of 100%

3.3. Effect of plastic ratio

Fig 9 and 10 illustrate the abrasion weight loss (AWL%) for samples examined at ages 3, 7, and 28 days for different plastic ratios of 0%, 30%, 60%, and 100%. In 28 days and at both 45° and 90° angles, the 100% plastic showed less deterioration than the other materials.

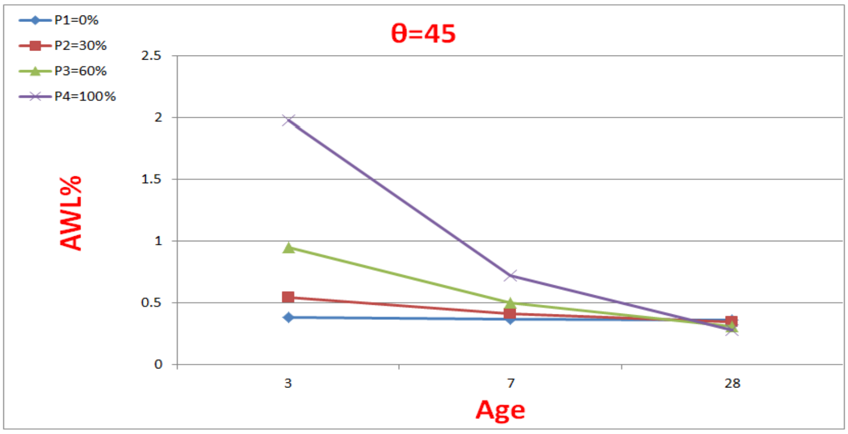


Fig 9. Depicts the corrosion damage at angle 45 and at 3, 7, and 28 days.

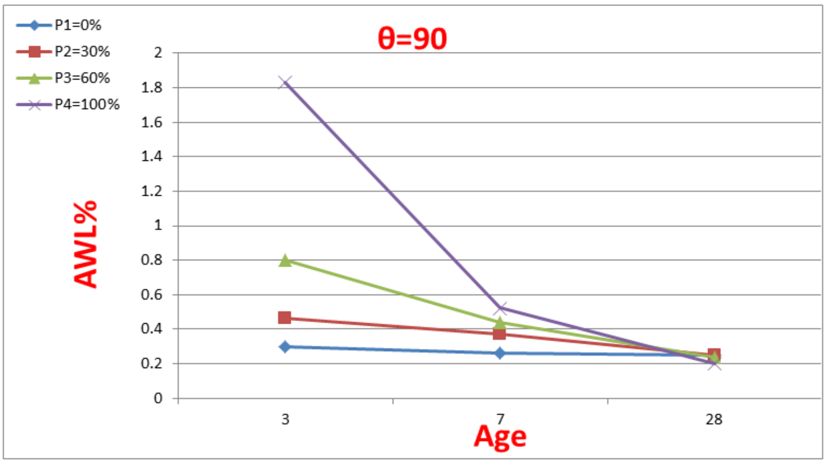


Fig 10. Depicts the corrosion damage at angle 90 and at 3, 7, and 28 days.

4. Conclusions

Numerous studies have been conducted on the use of various types of plastic waste as a partial replacement of aggregate in concrete. These studies demonstrated that plastic waste could be substituted for natural aggregate in a variety of applications. On the basis of this study's findings, the following inferences can be made:

- At all curing ages, the compressive strength values of all waste plastic concrete combinations have a tendency to fall below the values for the conventional concrete mixtures as the waste plastic ratio increases. This may be attributed to the weakness of the bond between the waste plastic's surface and the cement paste. Furthermore, since waste plastic is a hydrophobic, it may prevent cement from fully hydrating.

- In comparison to other sorts of plastic combinations, the 100% plastic ratio produced the highest abrasion resistance. Compared to the values of a conventional concrete mix, resistances were 62% lower.

- A 100% plastic mixture is the best option for use in hydraulic systems that are subjected to heavy abrasion because it has the highest abrasion resistance.

- Existing research indicates that incorporating various types of plastic aggregate into concrete will make it more resistant to chemical attack.

- According to the previous findings, the age of the concrete sample has a considerable influence on the rate of abrasion, as wear resistance increases with age and the compressive strength of green concrete grows with age.

- It was clear that a flow inclination angle of 45 showed the worst erosion damage. This happened because, in the instance of the perpendicular water jet (90), the impact of the water when it reaches the surface is what generated all of the pressure. When applied to inclined surfaces, however, pressure is split into two vehicles, with only the normal exerting a significant impact on the surface.

According to this study, waste plastic after grinding can be utilized as a replacement for coarse aggregate in the production of standard concrete. Previous research, however, did not employ plastic to withstand erosion in concrete.

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