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INVESTIGATING THE USE OF RECYCLED PLASTICS AS SHRINKAGE REINFORCEMENT IN NON-STRUCTURAL CONCRETE SLABS

دراسة إمكانية إستخدام البلاستيك المعاد تدويره كتسليح إنكماش في البلاطات الخرسانية الغير إنشائية

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ملخص البحث

هدف هذه الدراسة هو التحقق من امكانية استخدام مخلفات البلاستيك المعادة التدوير كتسليح للبلاطات الغير إنشائية حيث تم استخدام نوعين من البلاستيك المعاد تدويره في هذه الدراسة، الأول منها من البوليثيلين عالي الكثافة على شكل بلاستيك ممزق موزع بشكل عشوائي بالنسب 1% و 2% و 3% حجما. أما النوع الثاني فهو من البوليثيلين منخفض الكثافة المعاد تدويره بأشكال أسطوانية ذات قطر 3 مم، حيث تم عمل شبكات منها بالنسب 0.1 % و 0.2 % و 0.3 % من مساحة المقطع الخرساني وتم فحصها للانكماش الجاف. بالنسبة لإختبار الإنكماش الجاف فقد بينت نتائج الإختبارات أن إضافة ألياف البلاستيك المعاد التدوير تؤدي الى تقليل الإنكماش الجاف بل وبصورة أفضل من حديد التسليح المطاوع عند استخدامها بنسب معينة ولكن لها تأثير سلبي على مقاومة الشد والضغط للخرسانة، ولذا يوصى بإستخدام البلاستيك المعاد تدويره في الخرسانة الغير إنشائية.

Abstract

The aim of this study is to investigate the potential of using recycled plastics waste as reinforcement in non-structural concrete slabs. Two types of recycled plastics are used; the first is Recycled High Density Polyethylene in randomly-distributed shredded pieces for the percentages of 1%, 2% and 3%, by volume. The second type is Recycled Low Density Polyethylene, cylindrical in shape and 3-mm in diameter. Mesh reinforcement are made out of these fibers with the percentages 0.1%, 0.2%, and 0.3% and tested for drying shrinkage. The results show that adding recycled plastics to the concrete mix can limit drying shrinkage far better than steel reinforcement when used in certain percentages but it has a negative impact on both tensile and compressive strengths. Thus, it is recommended that recycled plastics can be used in non-structural concrete.

Key Words: Shrinkage Reinforcement; Drying Shrinkage; Slabs; Compressive Strength; Recycled Polyethyline.

1- Introduction

The non-decaying waste materials cause a waste disposal crisis, thereby, contributing to the environmental problems. Most of these materials are left as stockpiles, landfill material or illegally dumped in selected areas [1]. Research is being carried out on the utilization of waste products in concrete. Such waste products include discarded tires, plastic, glass and steel. The use of waste products in concrete not only makes it economical but also it helps in reducing disposal problems. One such waste is plastic, which could be used in various applications. However, efforts have also been made to explore its use in concrete [2]. Concrete is the most important building

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material. The only disadvantage of concrete is its brittleness. Fibers have been used since Biblical times to strengthen brittle materials. Since that time, the concept of dispersed fibers in cement-based materials has developed considerably [3]. Kou et al. [4], Batayneh et al. [1], Choi et al. [5] and Ismail and Hashmi [6] investigated concretes that are prepared with the use of recycled plastics. They reported that the workability, compressive strength, tensile splitting strength and workability of the concretes are reduced. Al-Manaseer and Dalal [7] investigated the effects of inclusion of plastic aggregates on the strength of concrete. They stated that the compressive and splitting tensile strength decrease with increasing the percentage of plastic aggregates. They also stated that there is an increase in slump when plastic aggregates are incorporated in concrete. Based on research results regarding the reduction in compressive and splitting tensile strength, some researchers recommended that concrete with plastic particles be used in non-structural concrete car3 [1]. The two principal types of shrinkage are plastic and drying shrinkage. Plastic shrinkage occurs while concrete is in the plastic state. Drying shrinkage occurs after concrete has reached initial set. Technically, drying shrinkage will continue for the life of the concrete but most shrinkage will occur within the first three or four months after placement. In the past, several techniques have been proposed for studying shrinkage induced cracking in cement based materials including a ring type specimen, a linear specimen with anchored ends, a linear specimen held between a movable and a fixed grip and a plate type specimen. These tests are well idealized in nature but do not represent the actual condition of restraints in practice. A technique producing restraints that is close to the one in reality was recently developed [2]. Alhozaimy [8], Alhozaimy and Shannag [9] and Alsayed [10] suggested that the addition of recycled plastic fibers to concrete can be used effectively for controlling plastic shrinkage cracking of concrete structures. In his study, Auchey [11] demonstrated that it is feasible to use recycled high density polyethylene fibers as secondary reinforcement for temperature and shrinkage influences in Portland cement concrete structures. Alsayed [10] carried out an experimental program to investigate the influence of adding polyolefin fibers (POF) on the drying shrinkage of concrete under laboratory and actual field condition. The test results showed that adding POF to the concrete mix can arrest drying shrinkage cracks. Kou et al. [4] investigated concretes that are prepared with the use of recycled plastic waste sourced from scraped PVC pipes to replace river. They reported that concrete made with scraped PVC and had lower drying shrinkage than normal aggregate concrete. This study aims to investigates the use of recycled plastics as reinforcement in non-structural concrete slabs. The benefits of this are two-fold; first to solve some of the solid waste problem posed by waste plastics and second by reducing the cost of materials. Although previous studies on the subject prove that recycled plastic fibers can reduce drying shrinkage in concrete, this research deals with using recycled plastics mesh reinforcement and gets into the practical ratios, spacing of these fibers and comparing it with steel shrinkage reinforcement specified by ACI318-08 [12].

2- Materials and mix design

2-1 Materials

Cement: Type I Portland cement conforming to ASTM C 150 [13] Standards is used in all concrete mixes used in the study.

Coarse aggregate: Crushed limestone with a specific gravity of 2.65 and an absorption capacity of 2.12 % is used as coarse aggregate.

Fine aggregate: Sand with a specific gravity of 2.36 and an absorption capacity of 1 % is used. Specific gravities and absorptions of coarse and fine aggregates conform to ASTM C 127 [14] and ASTM C 128 [15].

Mixing water: Tap water obtained from IUG Material and Testing Laboratories.

Steel reinforcement: Mild steel 1.5-mm in diameter with a yield stress of 300 MPa.

Recycled plastics: Two types of recycled polyethylene plastic fibers are obtained from a local recycling plant in Gaza City. The first is randomly distributed recycled shredded RHDP pieces ranging from 0.5 cm to 1.0 cm in length in fractions of 1 %, 2% and 3%, per volume. The second is RLDP wires, cylindrical in shape and having a 3-mm diameter in mesh distribution of 0.1%, 0.2% and 0.3% of the gross sectional area of concrete and having an ultimate tensile strength of 16 MPa (See Fig. 1. for photos of the two types).

Fig. 1-a. Recycled High Density Polyethylene (RHDP)

Fig. 1-b. Recycled Low Density Polyethylene (RLDP)

2-2 Mix proportions

The concrete mix is designed according to ACI 211.1 [16] to attain a compressive strength of 20 MPa at 28 days and a 100-mm slump with water to cement ratio of 0.69. Each cubic meter of the concrete mix consists of 685 kg/m^3 of sand, 1325 kg/m^3 of coarse aggregates, 225 kg/m^3 of cement and 165 kg/m^3 of water. For the ground RHDP fibers, four mixes with fiber contents of 0, 9.5 kg, 19 kg and 28.5 kg respectively.

2-3 Test Specimens

Twelve 100 mm x 100 mm x 100 mm cubic specimen, three for each percentage of RHDP are prepared to determine the compressive strength at 28 days based on ASTM C109 [17]. For the tensile splitting strength, twelve 6 inch by 12 inch cylindrical specimen, three for each percentage of RHDP are used to determine the strength at 28 days based on ASTM C496 [18]. The slump test is used to determine the workability of concrete based on ASTM C 143 [19], while ASTM C642 [20] is used to determine the hardened density at 28-days.

For the drying shrinkage test using RHDP, 9 slabs 500 x 500 x 40 mm in dimension are cast with recycled plastics contents of 1%, 2% and 3%. For drying shrinkage measurements using RLDP, 3 slabs 500 x 500 x 40 mm in dimension were cast for the percentages 0.1%, 0.2% and 0.3% of the cross-sectional area of concrete. The 0% recycled plastics slabs were reinforced by mild steel reinforcement as per article 7.12.2.1 of ACI 318-08 [12] Code placed at mid depth of the slabs and considered as control specimens. Each of the 15 slabs was cast on top of an old outdoor concrete floor slab cast years before while the newly cast slabs were restrained by steel shear spaced at 10 cm and fixed to the old concrete outdoor floor slab. For drying shrinkage measurements, datum discs were glued to the top surfaces of the slabs at 200 mm distances in two perpendicular directions one day after casting of the slabs.

A mechanical demec gauge model 58-C0230/20 manufactured by Controls Company, with a 200 mm gauge length and 0.001 mm resolution, is used for measuring the changes in length (See Fig. 2).

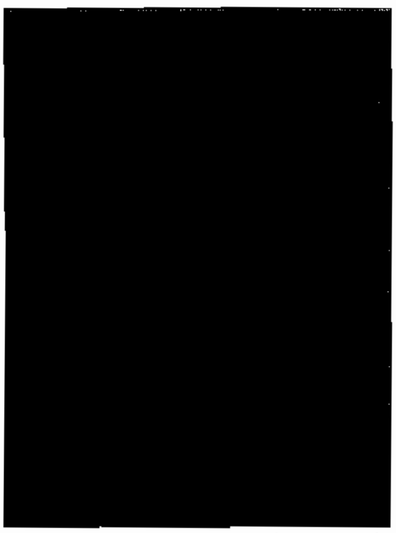

Fig. 2. Demec gauge datum discs

2-4 Mixing, casting and curing

Mixing was done in a tilting drum mixer as per ASTM C 192 [21]. The corresponding recycled plastics quantity was added gradually, blended into the concrete mixture and mixed thoroughly for additional 3 minutes. The compressive strength cubic specimens and the cylindrical specimens intended for tensile splitting strength were cast in the laboratory. After casting, the specimens were covered with burlap and thin polyethylene sheets for 24 hours before being demolded and placed in a curing tank until testing time. For the drying shrinkage slab specimens, the concrete was placed in the forms in one layer and consolidated using rodding. Curing was done twice daily over a two-day period to simulate local curing practices of such slabs and finishing of the surface was done using a wooden screed (see Fig. 3.a,3.b).

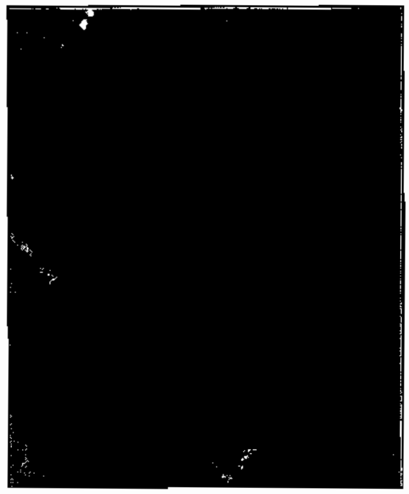

Fig. 3-a. Finishing the slab surface

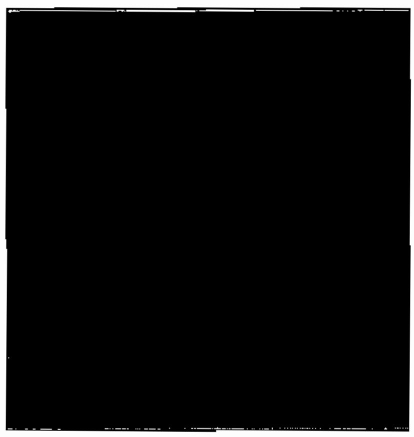

Fig. 3-b The cast slabs

3- Results and Discussions

3-1 Slump Test

The slump values for the different contents of RHDP fibers are shown in Fig.4., where it is observed that the addition of recycled plastics fibers has a negative impact on the slump values but the mixes used are still workable. For 1 % ratio of RHDP, the slump is reduced by about 17 % and at 3 % ratio the slump is reduced by about 30 % compared with plain concrete. This reduction may be attributed to the irregular shapes of RHDP fibers. This finding conforms with Batayneh et al. [1], Kou et al. [4], and Ismail and Hashmi [6], while it discords with Choi et al. [5] and Al-Manaseer and Dalal [7] who report decrease in slump values with inclusion of recycled plastics fibers.

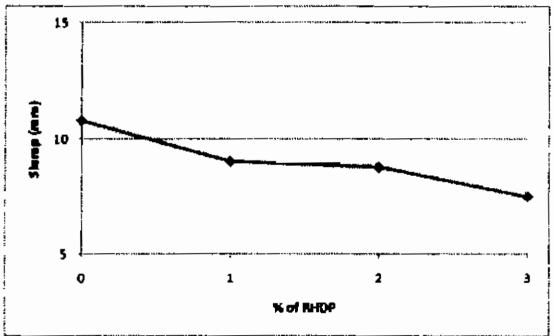

Fig. 4. Relationship between slump values and RHDP content

3-2 Compressive strength

The 28-day compressive strength values for the different contents of RHDP fibers are shown in Fig. 5., where it is observed that the addition of recycled plastics fibers has a negative impact on the compressive strength of concrete, with increasing the recycled plastics content. At 3 % RHDP content, the compressive strength drops by 12 % in comparison with the control concrete mix. This finding, in general, conforms with Bataynel et al. [1], Siddique et al. [2], Kou et al. [4], Choi et al. [5], Al-Manaseer and Dalal [7] , Ismail and Hashmi [6] and Alhozaimy and Shannag [9].

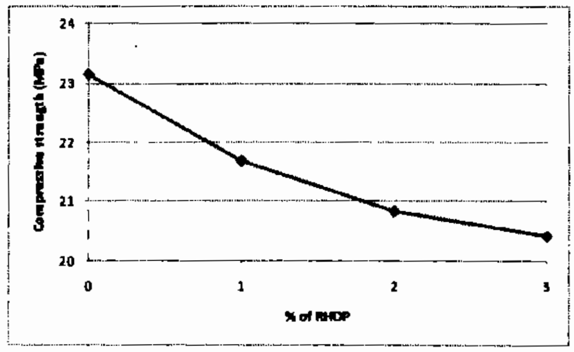

Fig. 5. Relationship between compressive strength and RHDP content

3-3 Tensile splitting strength

The 28-day tensile splitting strength values for the different contents of RHDP fibers is shown in Fig. 6., where it is observed that the addition of RHDP fibers has a negative impact on the splitting tensile strength of concrete when increasing the recycled plastics content. At 3 % RHDP content, the splitting strength drops by about 26 % in comparison with the control concrete mix. This finding, in general, conforms with Bataynel et al. [1], Siddique et al. [2], Kou et al. [4], Choi et al. [5], Al-Manaseer and Dalal [7], Ismail and Hashmi [6] and Alhozaimy and Shannag [9].

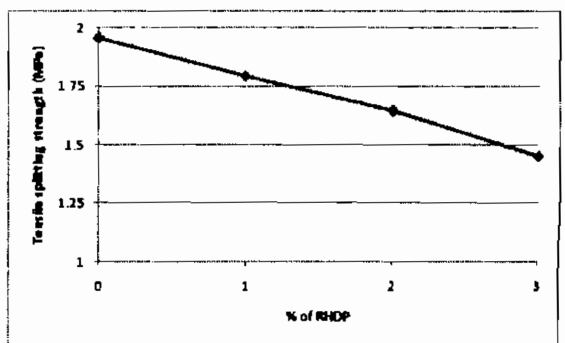

Fig. 6. Relationship between tensile splitting strength and RHDP content

3-4 Drying shrinkage

The measured strains at the end of the measured period of 85 days are shown in Table 1, where the percentages of RHDP and RLDP that reduce the drying shrinkage far better than the control slabs (using steel shrinkage reinforcement) are indicated by the values with negative sign. The same table shows that the control slabs reinforced with ACI 318-08 shrinkage reinforcement performed better than RHDP slabs in terms of reducing drying shrinkage for percentages lower than or equal to 2%. For RLDP slabs, the control slabs performed better for percentages lower than 0.2%. The average measured strains for control and recycled plastics slabs cured under field conditions are presented in Figures 7 through 9. Figure 7 shows drying shrinkage measurements for RHDP compared with those for shrinkage reinforcement. Figure 8 shows drying shrinkage measurements for RLDP compared with those for shrinkage reinforcement. Figure 9 shows drying shrinkage measurements for RLDP and RHDP contents which yield smaller drying shrinkage strains than ACI 318-08 [12] specified shrinkage reinforcement. As it is seen in Figures 7 through 9, the addition of recycled plastics to the concrete mixes result in increasing the rate of shrinkage at the beginning of the measuring period and but increases the ultimate shrinkage strains at the end of the measuring period. The findings of this study are in good agreement with available literature regarding RHDP, which is used effectively in reducing drying shrinkage [2, 4, 9, 10 and 11]. In terms of recycled RLDP mesh reinforcement, there are no results in the available literature to compare with.

Table 1: Recorded strains

Slab Type	Maximum Shrinkage (Micro Strain)	Increase in strain (%)
Steel Reinft.	330	-
1 % RHDP	406	23.03 %
2 % RHDP	356	7.80 %
3 % RHDP	210.8	-36.12 %
0.1% RLDP	370	12.00 %
0.2% RLDP	320	-3.00 %
0.3% RLDP	270.6	-18.18 %

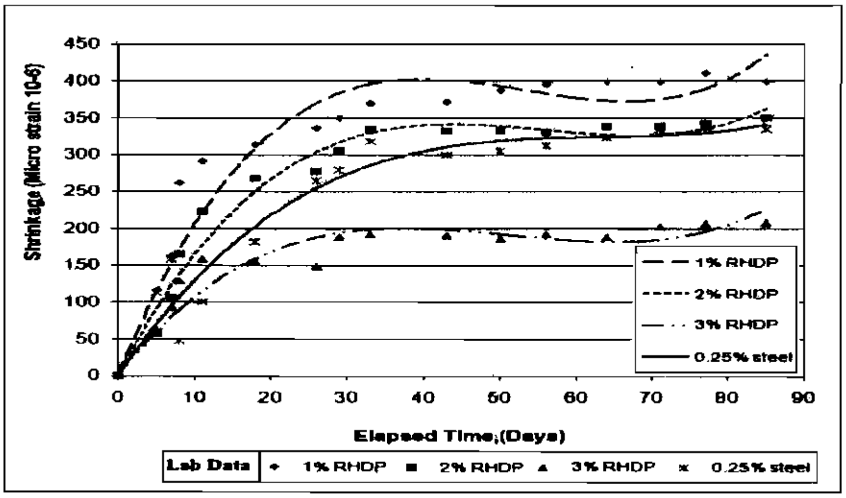

Fig. 7. Average drying shrinkage versus time for different RHDP contents

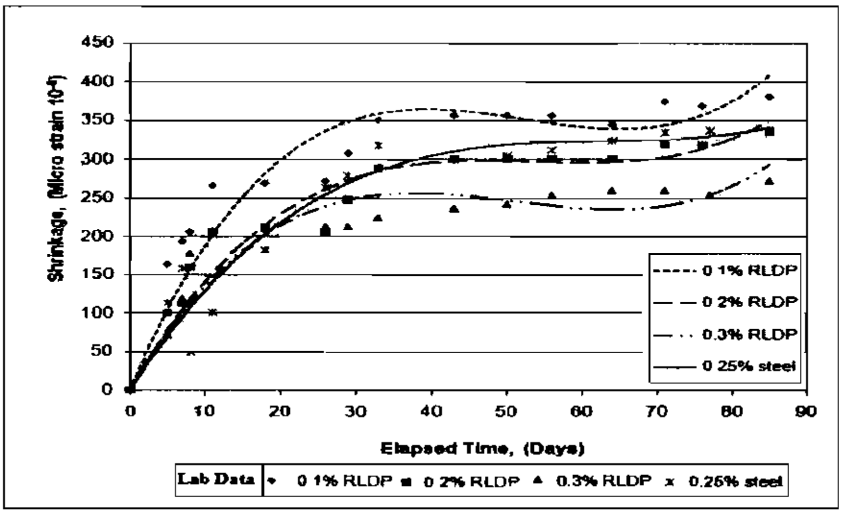

Fig. 8. Average drying shrinkage versus time for different RLDP contents

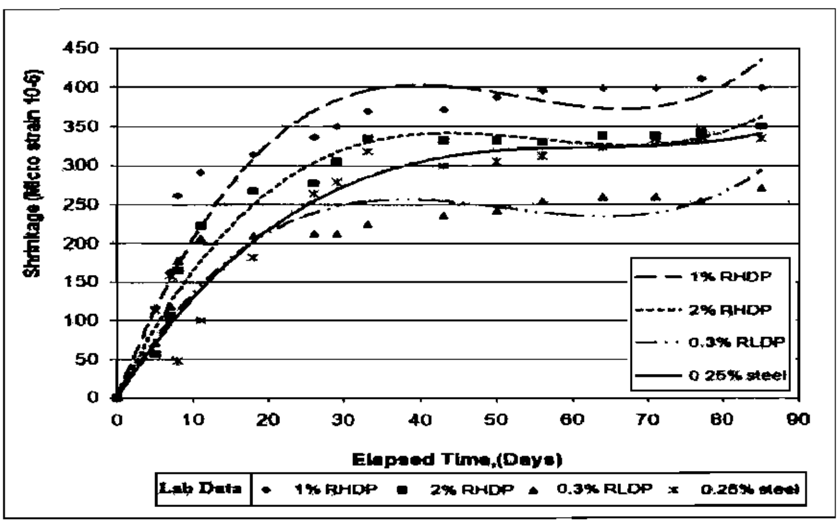

Fig. 9. Average drying shrinkage versus time for practical RLDP and RHDP contents

4- Conclusions

Based on the limited experimental work carried out in this particular research, the following conclusions may be drawn out as follows:

- The compressive and tensile splitting strength values of all fiber plastic concrete mixes tend to decrease below the values for the reference concrete mixes with increasing the fiber plastic ratio. This may be attributed to the decrease in the adhesive strength between the surface of the waste plastic and cement paste. So, it is advisable to use these fibers in concretes assigned for non-structural purposes.
- Randomly distributed recycled RHDP fibers can be used effectively as a replacement of steel shrinkage reinforcement specified by article 7.12.2.1 of ACI 318-08 Code. Ratios of 2% or more, by volume of recycled fibers give comparable or less drying shrinkage strains than steel reinforcement.
- Mesh prepared from recycled LHDP fibers can effectively be used as a replacement of steel shrinkage reinforcement specified by article 7.12.2.1 of ACI 318-08 Code. Ratios of 0.20% or more, by cross sectional area, give comparable, or less, drying shrinkage strains than steel reinforcement.
- The slump values of recycled plastic concrete mixtures show a tendency to decrease below the slump of the reference concrete mixture. In spite of this decline in the slump values of those mixtures, the mixtures are easy to work with based on the consideration that recycled plastics concrete is to be used in low-strength mixes.

•For other concrete mixes, types and shapes of recycled plastics and recycled plastic ratios, the results included in this particular study may not be held valid. Thus, more experimental work is needed for better understanding of the subject.

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