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Thermal conductivity and hardened behavior of eco-friendly concrete incorporating waste polypropylene as fine aggregate

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ABSTRACT

Waste polypropylene is one of the most common non-biodegradable solid wastes generated by industrial activity in Iraq. Solid waste is one of the several causes having a negative effect on the environment. The issues arise as a result of factors such as the difficulty of recycling waste and restricted reuse. Polypropylene is a significant kind of solid waste that has a negative impact on the environment. The purpose of this study is to determine the effects of using polypropylene as a partial replacement for sand in concrete. This material's effect on the fresh, mechanical, and thermal conductivity properties of concrete was investigated. Six concrete mixtures using polypropylene as a partial substitute for sand were produced at substitution percentages of 0%, 8%, 16%, 24%, 32%, and 40%. The slump, fresh and dry unit weight, compressive strength, and thermal conductivity properties of fresh and hardened concrete were determined. At various rates of concrete production, the results of the experiments demonstrated a decrease in unit weight and compressive strength. Thermal conductivity reduced 49.1% for the mix contained 40% of waste polypropylene and satisfied the lower limit strength for structural purposes.

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1. Introduction

The increasing growth of the construction industry necessitates an increase in the use of river sand as a conventional fine aggregate in civil engineering projects of all sizes. Anywhere river sand is depleted could happen, especially in areas that are not near rivers. Machine-made sand could become an easy and feasible alternative in this situation [1]. However, reusing of wastes is significant from a variety of perspectives. Saving and preserving natural resources, reducing pollution, and improving the efficiency of energy production are all made possible by this technology. Consider industrial byproducts and wastes as extremely important resources. that need to be treated and used in the proper manner [2].

As a result of the long biodegradation time of polypropylene waste, it is rational to use these materials in other sectors to reduce their environmental impact. Concrete is critical to the advantageous usage of these materials in building. While some of these waste materials can be beneficially incorporated into concrete, either as part of the cementitious binder phase or as aggregates, it is important to remember that not all waste materials are suitable for this application. For example, some waste materials are toxic and should not be used in concrete [2].

The production of lightweight construction materials is regarded as beneficial for promoting the reuse of materials. Typically, replacing natural aggregates with lightweight materials results in a reduction in the unit weight of concrete. Weight reduction is a critical objective in the building business. There are numerous advantages to lightweight concrete, including increased thermal insulating response of the building and a reduction in the amount of money and time needed to handle and manufacture it [3]. In part because the self-weight of created structures is linearly related to seismic forces, the impact of an earthquake is reduced when the self-weight of the structure is reduced [4].

Furthermore, Mohammed et al. [5] studied whether the usage of PET as sand in self-consolidating concrete had a negative

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influence on the diameter of the slump flow and the compressive strength of the concrete. Meanwhile, Záleská et al [6] concluded that the mechanical characteristics and thermal conductivity of concrete mixtures decreased with increasing different waste plastic with different shape replacement as fine aggregate up to 50%. Moreover, Benosman et al [7] reported that using of PET in cement concrete composite had negative effect on workability, compressive strength and UPV but had the positive effect on thermal conductivity. The thermal behavior of concrete is essential to any application, but is particularly important in structures where thermal conductivity low, dimensional stability, a high specific heat, and little or no stiffness loss upon heating are desired. Moreover, there were many investigators studied on the effect of various pozzolanic materials on the fresh and hardened characteristics of concrete such as fly ash [8 –14], waste ceramic powder [15–17], ground granulated blast furnace slag (GGBFS) [18] and eggshell powder [19] which reported the positive impact on the hardened characteristics.

However, the effect of polypropylene particles as a substituent to river sand in concrete production and its effect on concrete properties has not been previously reported. As a result, this experimental investigation illustrated the possible use of polypropylene as fine lightweight aggregate in eco-friendly concrete production. For that instance, the different percentages of polypropylene were used to produce sustainable concrete mixtures. Consequently, the impact of six different percentages replacement levels of 0, 8, 16, 24, 32 and 40% in volume on fresh, density, compressive strength and thermal conductivity properties was studied.

Table 1
Physical and chemical properties of Portland cement and limestone powder.

Chemical properties	Portland cement (%)	Limestone powder (%)
CaO	61.0	53
SiO_2	21.0	0.21
Al_2O_3	3.0	11.25
MgO	2.82	0.17
Fe_2O_3	5.4	2.66
SO_3	2.37	0.36
K2O	1	0.04
Na2O	0.19	–
L.O.I %	1.59	41.55
Fineness Blain (m^2/kg)	350	630
Specific gravity	3.15	2.65

2. Experimental program and materials

2.1. Materials

In this paper, the ordinary Portland cement (OPC) type CEM I 42.5 N with specific gravity of 3.15 was utilized according to the Iraq specification standard IQS 5 /2019 [20]. Limestone powder was used as 25% of total binder content in the all mixtures. The physical and chemical properties of OPC and limestone powder are demonstrated in Table 1.

In this study, the local natural sand and the river gravel were utilized as fine and coarse aggregates with maximum size of 4.75 and 14 mm, respectively. Aggregates were tested following the IQS 45/1984 [21]. Coarse aggregate and fine aggregate has a specific gravity of 2.7 and 2.65, respectively.

As part of this investigation, the recycled waste polypropylene (WPP) was used to replace a percentage (by volume) of natural sand inside concrete mix compositions to improve in the concrete production. The WPP was obtained from industrial boxes which closed and tight with these polypropylene tapes. Fig. 1 illustrated the WPP. However, WPP had a specific gravity of 0.92 and a water absorption of 0 percent, respectively.

2.2. Mix proportions

The reference concrete mixture consisted of 732 kg/m^3 sand, 1080 kg/m^3 gravel, 285 kg/m^3 cement, 95 kg/m^3 limestone powder and a W/C ratio of 0.52. This mixture was contained 0% of waste polypropylene (WPP) and were cured for 7 and 28 days. The con-

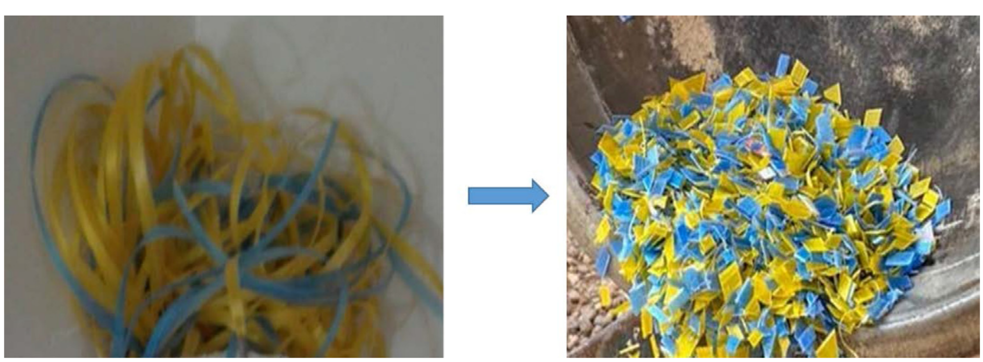

Fig. 1. Waste polypropylene sample.

Table 2
Mix proportions in (kg/m^3).

Mix ID	Cement	Limestone powder	w/b	Water	Fine aggregate		Gravel
					River sand	Polypropylene sand	
R	285	95	0.52	197.5	732	0	1080
WPP8	285	95	0.52	197.5	673.4	20.3	1080
WPP16	285	95	0.52	197.5	614.9	40.6	1080
WPP24	285	95	0.52	197.5	556.3	61	1080
WPP32	285	95	0.52	197.5	497.8	81.3	1080
WPP40	285	95	0.52	197.5	439.2	101.6	1080

Fig. 2. Compressive strength test.

Fig. 3. Thermal conductivity test.

crete mixtures contained WPP are presented in Table 2 as WPP8, WPP16, WPP24, WPP32 AND WPP40, corresponding to the 8%, 16%, 24%, 32% and 40% addition of WPP as sand replacement, respectively.

2.3. Testing procedures

There were many tests performed after the mixing of ingredients to produce a fresh concrete mixture. The slump test was performed with respect to B.S.1881, part 2 [22]. Then, the fresh and dry density values were computed on a 15 cm cubic after instantaneous compacting in accordance with B.S.1881, section 5 [22] at 7 and 28 day curing ages. The compressive strength was performed on 15 cm cubic according to ASTM C39M– 20 [23] specifications at curing ages of 7 and 28 days as illustrated in Fig. 2. Thermal conductivity test was calculated according to ASTM C1363-19 [24] specification procedures as shown in Fig. 3. All tests used three 15 cm cubic.

3. Results and discussion

3.1. Slump test

Fig. 4 illustrates the outcomes of slump testing on concrete mixtures partially contained waste polypropylene (WPP). These findings indicate that the slump is disposed to reduce quickly when the WPP ratio increases. For WPP8, WPP16, WPP24, WPP32, and WPP40, slump reductions are 53.8, 61.5, 72.3, 76.9 and 80.7%, respectively. There is a possibility that this loss is caused by the fact that certain particles are angular and others have non-uniform shapes, which results in decreased fluidity. The findings are consistent with the findings of other researchers [5,7].

3.2. Fresh density

Fig. 5 illustrates the wet densities of WPP concrete mixtures. The data reveal that the fresh density of WPP8, WPP16, WPP24,

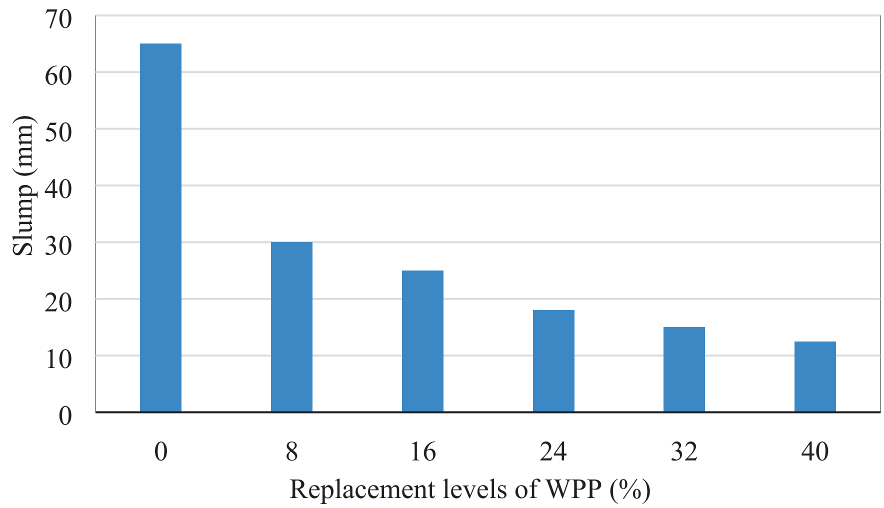

Fig. 4. Slump of waste polypropylene concrete.

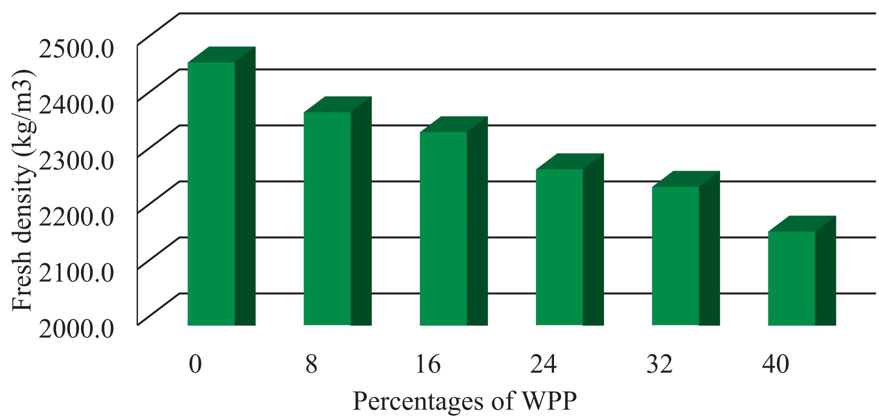

Fig. 5. Fresh concrete density with varying WPP content.

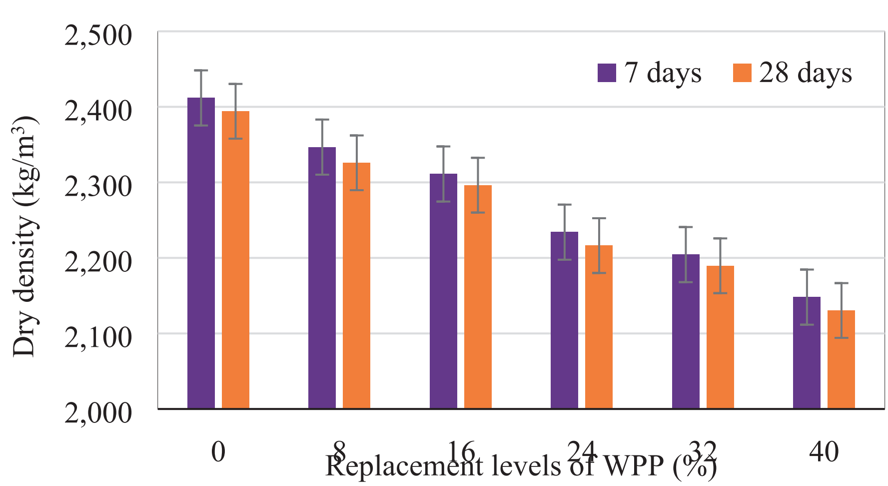

Fig. 6. Dry density of concrete with variation WPP content.

WPP32 and WPP40 tends to drop by 3.6, 5.1, 7.8, 9.1, and 12.3%, respectively. WPP has a lower density than sand by a factor of 65.2%, which results in a decrease in fresh density.

3.3. Dry bulk density

The dry density of concrete mixtures contained various ratios of WPP are illustrated in Fig. 6. The dry density of the mixtures were calculated at 7 and 28 days curing age. Increasing the proportion of WPP in a concrete mix tends to lower the dry densities at each curing age. From the outcomes of this study concluded that 2130.4 kg/m^3 was the lowest value of dry density but greater than the upper limitation for structural lightweight at 28 days curing age. The dry density of concrete contained 40% of WPP reduced 65.2% as compared with the reference concrete. The findings are fulfil with the outcomes of other investigators [5,7,13,15 –18].

3.4. Compressive strength

Fig. 7 depicts the effect of various WPP ratios on the compressive strength of concrete at different curing ages of 7 and 28 days. As the WPP concentration in the mixtures increases, the compressive strength of the mixtures falls below that of the reference mix at each curing age. This trend is due to a decrease in the adhesive strength between the WPP's surface and the cement paste, as well as a rise in the particle size of the WPP. As a result of its hydrophobic nature, WPP may prevent water required for cement hydration from permeating the concrete sample' structure during the cure period. The compressive strength of structural concrete must be at least 17.24 MPa, and all of the compressive strength values are above that at 28 days curing age. However, the outcomes are fulfil with the previous findings by researchers which demonstrated that the increasing replacement level of normal aggregate with lightweight aggregate led to the decline in the compressive strength of concrete or mortar [8,11,13,15–18,25,26].

3.5. Thermal conductivity

The thermal conductivity of concrete was determined after 28 days. The calculated thermal conductivity (k) values for the manufactured concrete, as determined by the experiments, are presented in Fig. 8. The results indicated that the thermal conductivity of control concrete was 2.07 W/(m.K) then tends to decline by 6.6, 26.8, 27.1, 28.3 and 49.1% for the mixes WPP8, WPP16,

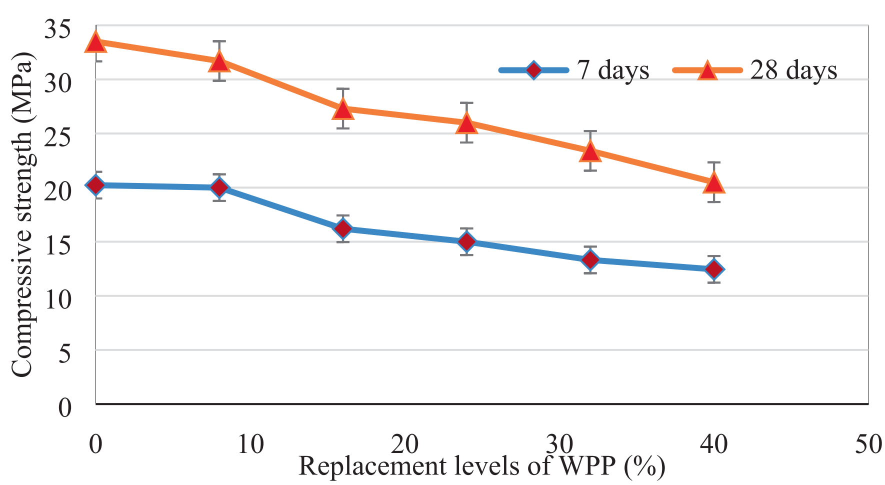

Fig. 7. Compressive strength of concrete with variation WPP content.

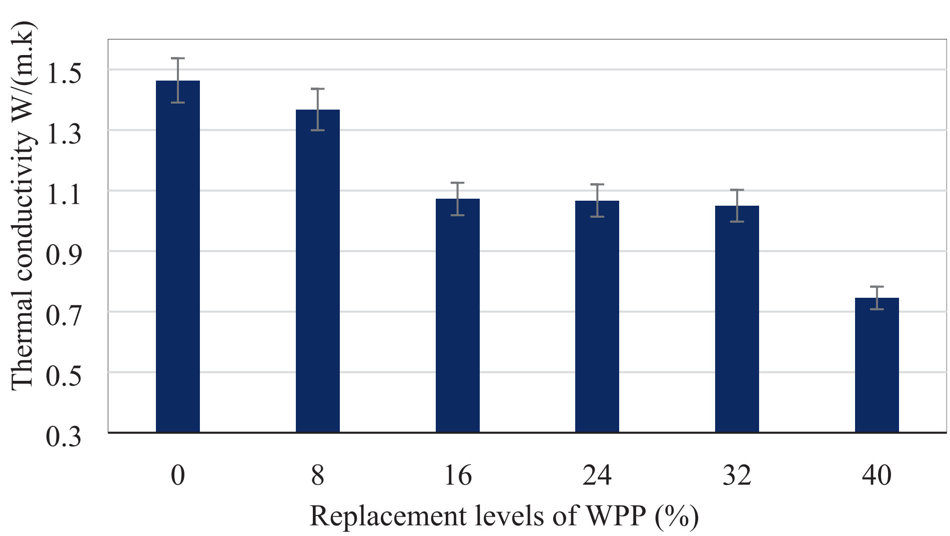

Fig. 8. Thermal conductivity of concrete with variation WPP content.

WPP24, WPP32 and WPP40, respectively. The causes for the decrease in thermal conductivity as the WPP content increases could be related to the WPP's behavior and the formation of voids, particularly at higher WPP percentages. The results coincide with the previous studies [7,27]. Therefore, it is a suitable recycled material for concrete production specially for the hot countries like Iraq.

4. Conclusion

In this study, the impact of recycling waste polypropylene as fine aggregate on the fresh, compressive strength and thermal conductivity of normal concrete mixtures was studied. The following are the major conclusions reached from the outcomes of this experimental investigation:

1- The compressive strength of concrete contained WPP tends to decline below those of reference concrete mixture as the WPP ratio increases. This could be explained by a reduction in the adhesive strength between the WPP of the surface and the cement paste. Moreover, WPP is a hydrophobic substance that may inhibit cement hydration.
2- The dry densities of WPP concrete mixtures tend to be lower than those of the control mixture at both curing ages. The lowest dry density 2130.4 kg/m^3 at 28 days of curing is more than the range of structural lightweight concrete's dry density.
3- The outcomes of fresh density reduced as substitution level of WPP rised in the concrete comparing to the reference mix.
4- Comparing to the control mix, the slump value of the concrete declined by increasing WPP content in the mixtures.
5- Thermal conductivity of concrete reduced 49% by replacing 40% of river sand with WPP and satisfied the minimum value required for structural application. In practice, This method of production has the advantages of being more environmentally friendly and more sustainable, as well as partially eliminating issues linked with polypropylene waste disposal and mitigating issues associated with temperature, particularly in Iraq.

CRediT authorship contribution statement

Sulaiman Nayef Ahmed: Methodology, Resources. **Nadhim Hamah Sor:** Conceptualization, Validation, Data curation, Writing – original draft, Writing – review & editing. **Mohammed Akram Ahmed:** Visualization, Investigation. **Shaker M.A. Qaidi:** Validation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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