Journal of Science and Technology in Civil Engineering, HUCE, 2023, 17 (3): 33–45

SUSTAINABLE UTILIZATION OF MIXED HEALTHCARE WASTE AS AGGREGATE IN LIGHTWEIGHT CONCRETE MIXES: MECHANICAL BEHAVIOR, WATER ABSORPTION AND LEACHING STUDIES

Lubna K. Hamada[a], Zainab Z. Ismail[a,*], Anita Závodská[b]

[a]*Department of Environmental Engineering, University of Baghdad, Baghdad, Iraq*
[b]*Barry University, Miami, Florida, United States of America*

Article history:
Received 10/4/2023, Revised 17/6/2023, Accepted 27/6/2023

Abstract

Wastes generated from healthcare practices are a serious problem for humans as well as for the environment. In this study, an attempt was made to use mixed solid medical waste (WPN) which consisted of shredded waste plastic and chopped waste needles for partial replacement of natural fine aggregate (sand) in concrete mixes at 0%, 2%, 4%, 6%, 8% and 10% by weight. To examine the validity of the suggested approach, the fundamental concrete properties including workability, fresh and hard densities, water absorption, compressive strength, and flexural strength as well as a leaching test were performed. The curing ages for the concrete mixes were considered to be 7, 14, and 28 days. Fifty-four cubes were molded for compressive strength test, and 72 prisms were cast for flexural strength, whereby 162 cubes were prepared for density tests as well as water absorption test. The results revealed that WPN-concrete mixes exhibited improvement in the workability and steadily decreased both the compressive and flexural strength values of the WPN-concrete mixes which were higher than the mean target strength of lightweight concrete grade M17. Leaching test results indicated the absence of the target components in the leachant. The outcomes of this experimental study demonstrated that reusing WPN as a sand-substitution aggregate in concrete is a good approach to reducing the adverse impact resulting from the improper management of healthcare and medical solid waste.

Keywords: waste management; healthcare waste; aggregate; recycling; concrete mixes.

https://doi.org/10.31814/stce.huce2023-17(3)-03

1. Introduction

Biomedical waste derived from healthcare activities is a serious concern for environmentalists [1]]. Biomedical operations lead to increases in the amount of waste that may have effects. The generation of healthcare waste across the developing countries ranges from 0.1 to 6.0 kg/bed/day [2]. The properties of biomedical waste are dictated by their composition [3]. Medical waste which is a type of hazardous waste includes genotoxic products, infectious agents, toxic drugs and chemicals, sharp instruments and hazardous materials [4]. Effective management of hospital and medical waste has become a potential environmental issue and green healthcare aspect as well [5]. On the other hand, concrete is the world's leading construction material in the world today [6]. It is the most commonly used in all kinds of civil engineering work, including infrastructure, low-rise and high-rise buildings, environmental conservation, and local/domestic developments. Modern times require new building materials and processes to be implemented to keep up with the demand for new construction. Silva et al. [7] investigated the influence of curing conditions on the durability of concrete mixes containing polyethylene terephthalate plastic waste aggregates. The results revealed a decline in durability

*Corresponding author. *E-mail address:* dr.zainab.zead@coeng.uobaghdad.edu.iq (Ismail, Z. Z.)

compared to conventional concrete. Khilesh [8] studied the compressive strength of concrete using waste plastic and steel fiber. The results indicated a percentage decrease in 7 and 28-days compressive strength. Verma et al. [9] concluded that the replacement of natural sand in concrete with polyethylene bottles (PET) affected the concrete's compressive strength. Arivalagan [10] examined the properties of concrete mix that contains waste plastic with up to 10% addition of plastic aggregate replacing traditional aggregate. This provided strength within the allowable limit and decreased concrete density while increasing workability because the plastic used as aggregate was smooth. Jaivignesh and Sofi [11] explored the effect of partial substitution of natural aggregates with non-biodegradable plastic aggregates on the characteristics of waste plastic-modified concrete. The results demonstrated that the mechanical characteristics of the waste plastic-modified concrete had been reduced most likely due to the weak bonding between the plastic aggregate and cement in the concrete mix. Kannan and Harikrishnan [12] studied the effect of a 10% to a 40% partial substitution of natural aggregate by hospital waste plastic aggregates in the concrete grade of M30. Based on the findings, after a 40% replacement of the hospital waste aggregate, the compressive strength of concrete was reduced. Hamada and Ismail [13] investigated the effect of incorporating medical needle waste (MNW) for partial replacement of aggregate in lightweight concrete mixes. The results revealed improvement in the flexural strength and workability of MNW-modified concrete. However, none of the previously reported studies considered the application of mixed types of medical solid wastes to replace the natural aggregate in concrete mixes. Ho and Huynh [14] investigated the validation of recycling waste medical glass to replace the fine aggregate in low environmental impact concrete and its effect on long-term strength and durability performance. The results demonstrated that all tested concrete mixes met the classification standards for very good quality.

The present study aimed to assess the validity of incorporating mixed healthcare solid waste including waste plastic and needles in concrete mixes as a sustainable safe path for dealing with this specific hazardous type of waste. A leaching test was conducted to assess the ability of concrete to retain the healthcare solid waste. Also, the influence of the partial replacement of natural aggregate by the mixed healthcare solid waste on the fundamental mechanical properties of the modified concrete mixes was examined.

2. Materials and methods

2.1. Mixed medical solid wastes

Medical solid waste (WPN) consisted of a mixture of shredded plastic waste and used chopped needles were utilized to partly replace the fine aggregate in concrete mixtures. This waste was provided by healthcare centers, regional hospitals, and private clinics. The chopped plastic waste consisted of plastic syringes, blood and fluids bags as well as the plastic parts of medical accessories such as cannulas, tubes, and adapters. The plastic and needle waste were sterilized after collection, and then the waste was shredded and chopped to get the required size, with a maximum size of 5 mm. Table 1 and Fig. 1 illustrate the physical characteristics of waste plastic and needles, respectively. The WPN didn't undergo any chemical processes or were mixed with and exposed to any chemicals before use in the concrete mixes. Fig. 2 shows samples of the crushed healthcare waste.

2.2. Concrete materials

Type 1 ordinary Portland cement was used in all concrete mixes. The chemical analysis and physical characteristics of the cement are given in Tables 2 and 3, respectively. Natural sand was used as a fine aggregate of a maximum size 5 mm. The sand properties and sieve analysis are presented in Table 4 and Fig. 3, respectively. Natural crushed stones were used as coarse aggregate with a maximum size of 20 mm and a bulk density of 1500 kg/m^3. The physical characteristics of the coarse aggregate are shown in Table 5, whereby its sieve analysis is given in Fig. 4.

Table 1. Physical properties of the waste plastic and needles

Properties	Results	
	Shredded waste plastic	Chopped needles
Material	Polypropylene (PP)	Stainless steel
Bulk density (kg/m^3)	320	1455
Size (mm)	≥ 5	15-20
Shape	Aboard distribution dimensions of fabriform with varying length and width	Fine cylindrical shape
Color	Mainly white and colorless (transparent)	Silver gray

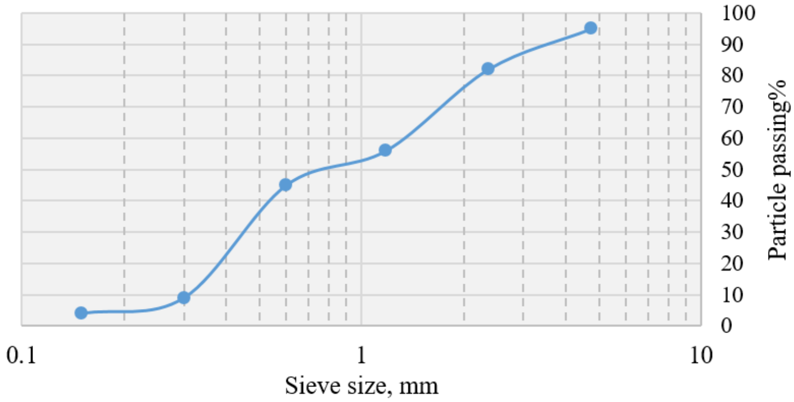
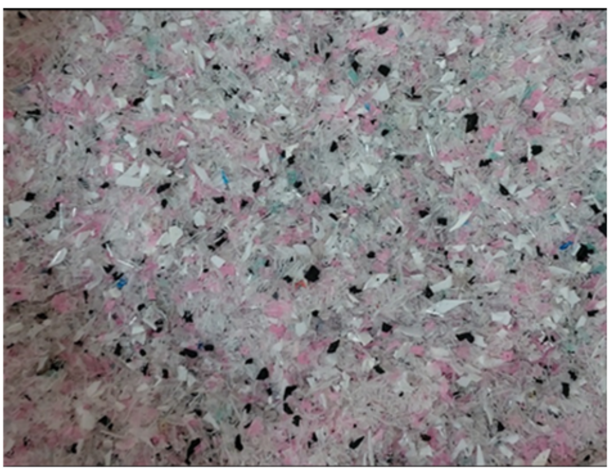


Figure 1. Sieve analysis of the shredded waste plastic



(a) Waste plasti

(b) Waste needles

Figure 2. Samples of crushed medical waste

Table 2. Chemical composition of cement

Compounds	Abbreviation	Weight (%)
Lime	CaO	61.65
Silica	SiO_2	21.25
Alumina	Al_2O_2	4.40
Iron oxide	Fe_2O_3	3.30
Sulfite	SO_3	2.10
Magnesia	MgO	1.89
Loss of ignition	L.O.I	1.58
Lime saturation factor	L.S.F	0.89
Insoluble residue	I.R	0.49
Tricalcium silicate	C_3S	48.13
Dicalcium silicate	C_2S	26.43
Tricalcium aluminate	C_3A	6.30
Tetra calcium aluminoferrite	C_4AF	8.96

Table 3. Physical properties of cement

Compounds	Abbreviation	Limits of cement	Limit of I.Q.S No. 5/1984
Finesse (m^2 /kg)	–	300	≥ 230
Initial setting time (min)	I.S.T	131	≥ 45 min
Final setting time (h)	F.S.T	240	≤ 10h
Soundness (%)	–		≤ 0.8
3 days age compressive strength (Mpa)	C_s	24	≥ 15
7 days age compressive strength (Mpa)	C_s	35	≥23

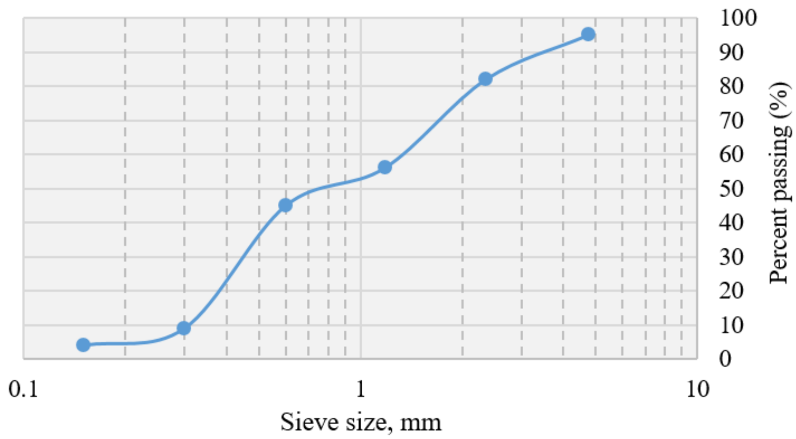


Figure 3. Sieve analysis of sand (fine aggregate)

Table 4. Physical properties of sand

Properties	Value	Limit of I.Q.S No. 45/1984
Specific gravity	2.56	–
Bulk density (kg/m^3)	1660	–
Absorption (%)	1.20	–
Sulfate content (as SO_3) (%)	0.13	0.5 (Max.)

Table 5. Physical properties of gravel (coarse aggregate)

Properties	Results	Limit of I.Q.S No. 45/1984
Specific gravity	2.52	–
Bulk density (kg/m^3)	1500	–
Absorption (%)	0.50	–
Sulfate content (as SO_3) (%)	0.014	0.5 (Max.)

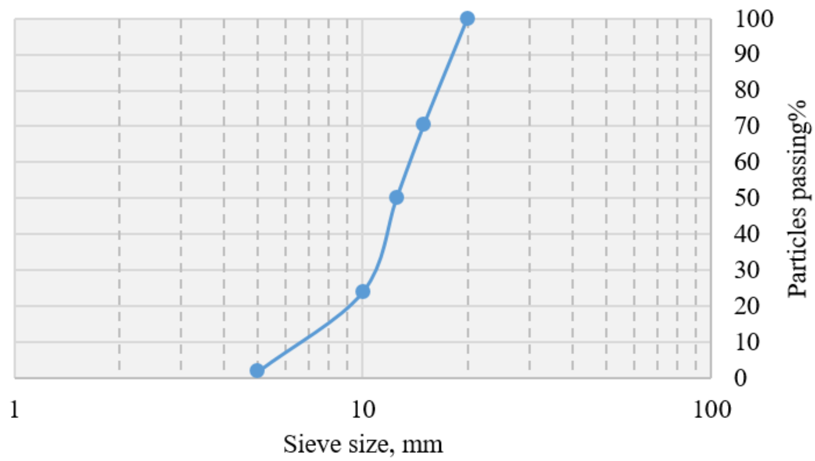


Figure 4. Sieve analysis of gravel (coarse aggregate)

2.3. Mixture proportioning

With 380 kg/m^3 cement, 715 kg/m^3 sand, 1020 kg/m^3 gravel, and a water to cement (W/C) ratio of 0.46, the plain concrete mixtures (WPN0) were set. The waste modified-concrete composites were prepared using WPN mix to partially replace the sand by 2%, 4%, 6%, 8% and 10% (weight %) in 5 mixes designated as WPN1, WPN2, WPN3, WPN4 and WPN5, respectively as given in Table 6. The mixture proportioning was designed according to the absolute volume method given by the American Concrete Institute (ACI). At the beginning of the mixture design, as the maximum aggregate size is 20 mm, it was appropriate to make the first trial mix using equal volumes of fine and coarse aggregate [15]. The cement content (380 kg/m^3) and water–cement ratio (0.46) were chosen for the mix (WPN0). A partial replacement of sand by weight was achieved at mixes (WPN1-WPN5), and then the weight and the volume of the ingredients for each mix were determined depending on the assumption that 3% air is trapped in fresh concrete. All mixes were designed based on a slump of (50–80 mm). The concrete mixes were cured for 7, 14, and 28 days according to ASTM C192 [16].

Table 6. Mixing proportions

Concrete mix symbol	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	W/C	WPN (kg/m^3)
WPN0	380	715.0	1020	0.46	0
WPN1	380	700.7	1020	0.46	14.3
WPN2	380	686.4	1020	0.46	28.6
WPN3	380	672.1	1020	0.46	42.9
WPN4	380	657.8	1020	0.46	57.7
WPN5	380	643.5	1020	0.46	71.5

2.4. Specimens preparation and test

One hundred sixty-two cubes of concrete, each of size 100×100×100 mm was prepared for fresh and hard density tests as well as water absorption tests. For compressive strength and flexural strength tests, 54 cubes of size 150×150×150 mm, and 72 prisms of size 70×70×380 mm were prepared, respectively. For the leaching test, 9 cylinders of size 50 x100 mm were molded.

Casting, compaction and curing were conducted according to B.S.1881:1952 [17]. Concrete casting was accomplished in three layers of 50 mm each. The layers were compacted using a vibrating table for 1–1.5 min until no air bubbles emerged from the surface of the concrete mold, then they were kept to dry at room temperature. After 24 h the concrete was removed from the molds, marked and submerged in fresh, clean water ready to be tested.

The slump test was carried out according to ASTM C143-05 [18]. The internal surface of the mold was thoroughly cleaned and freed from superfluous moisture before conducting the test. The mold was placed on a smooth, horizontal, rigid and nonabsorbent surface metal plate, and then filled with four layers. Each layer is one-fourth the mold height and was tamped with 25 strokes of the rounded end of a tamping rod. The strokes were distributed in a uniform manner over the cross-section of the mold, and for the subsequent layers, penetrated into the underlying layer. The mold was removed from the concrete by raising it in a vertical manner and then allowing the concrete to subside. The slump was then measured immediately by determining the difference between the height of the mold and the highest point of the specimen. Fresh density and dry density tests were conducted according to B.S.1881:1952 [17].

The fresh densities were measured immediately after the molding and compaction of the cubes. The dry densities were measured following the curing of the cubes in water, while they were wet, and just prior to achieving compression strength. The compressive strength tests were carried out according to B.S.1881:1952 [17]. A Forney-type machine was used for this test. The cubes were tested while they were still wet. The average compression strength of 3 cubes was recorded for each curing age. The flexural strength test was carried out according to ASTM C293-79 [19]. A 10 kN capacity proving ring and a dial gauge were used for these tests. The procedure consisted of setting the load of the center point to the sample until there was a failure. The average flexural strength of 3 prisms was recorded for each testing age. The water absorption test was performed in conformance with ASTM C 642-97 [20]. The specimens were dehydrated in an oven at 100–110°C for up to 72 h.

For concrete microstructure assessment, there are different methods including mercury intrusion porosimetry, light optical microscopy with an associated digital image analysis, scanning electron microscopy, and X-ray computed tomography with image processing. In this study, the light optical microscope was used to investigate the concrete microstructure.

Leaching tests are frequently used to assess the potential risk of a waste releasing contaminants from the hardened concrete containing waste into the environment. Simply, this test involved the placement of the prepared WPN-concrete cylindrical specimen in a transparent plastic container, and then the leaching solution (distilled water) was added to produce leachate. The specimen was fully immersed in the leaching solution. The container was tightly closed and maintained at ambient temperature.

Leaching tests for the WPN-concrete mixes were performed after 28, 120, and 180 days of curing in accordance with JSCE-G 575-2005 [21].

3. Results and discussions

Outcomes of assessing the mechanical characteristics of the WPN-concrete mixes and the leaching test was as follows:

3.1. Workability test (Slump)

The results of workability revealed that the slump values decreased as the content of WPN aggregate in the WPN-concrete mixes increased. The slump values of the WPN1, WPN2, WPN3, WPN4 and WPN5 mixes were comparatively lower than the plain mix's slump values (WPN0) as shown in Fig. 5. However, the WPN modified-concrete mixes were still workable despite this decrease in slump values. The reduction of the slump values may be due to the heterogeneity of distribution of the waste material in addition to the sharp and pointy shapes of the grains of the waste particles compared to the particles of sand. Increasing the content ratio of the mixed waste caused more cement paste to be attached to the waste surface, reducing the available cement paste needed for concrete fluidity. Ismail and Al-Hashmi [22] suggested a similar observation when using a mixture of plastic and iron filings for partial replacement of sand in concrete mixes. These findings are consistent with evidence reported by Sabale and Ghugal [23]. Due to the various types and shapes of fiber content, the slump values changed. Fibers tend to absorb more cement paste to wrap around because of the high content and huge surface area of fibers, while also increasing mixture viscosity which causes the loss of slump.

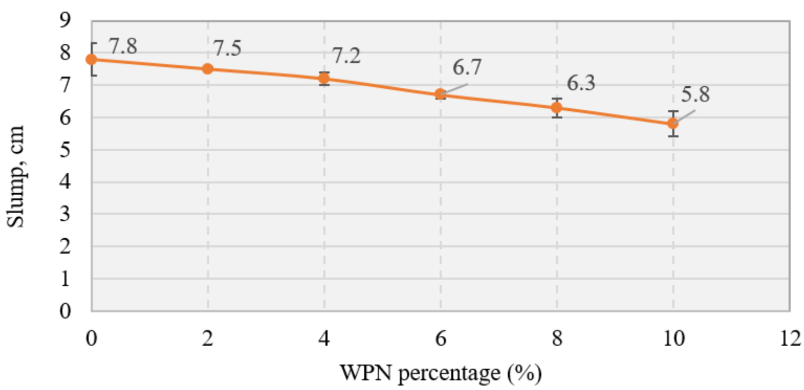


Figure 5. Profile of slump values for WPN-concrete mixes

3.2. Fresh and dry density tests

Results of the fresh density test for the WPN-concrete mixes are presented in Fig. 6. The results demonstrated that with increasing the WPN content, the fresh density values of WPN-concrete mixes were lower than the density value (2456 kg/m^3) for the control mix (WPN0). The fresh density values for WPN-concrete mixes including WPN1, WPN2, WPN3, WPN4, and WPN5 were 2450.3, 2446.2, 2442.5, 2438.5, and 2433.7, respectively. The expected reason behind this reduction in density values could be attributed to the fact that the density of the WPN was lower than the sand density (Tables 1 and 5) The test of dry density for WPN-concrete mixtures is presented in Fig.7. With increments in the waste ratio, the dry densities of the WPN-concrete mixes decreased at each curing age. Nevertheless, the dry density profiles maintained the same trend of increasing dry densities with time regardless of the percentage of WPN content. However, the results revealed that the lowest dry density was 2363 kg/m^3 obtained at 28 days curing age with WPN5. In spite the of decreasing trend in dry density values with increasing the WPN values at 28 days, all of the values including the lower value (2363 kg/m^3) were higher than the minimum acceptable density for light weight at 28 days which is equal to 1840 kg/m^3 specified by the American Concrete Institute (ACI).

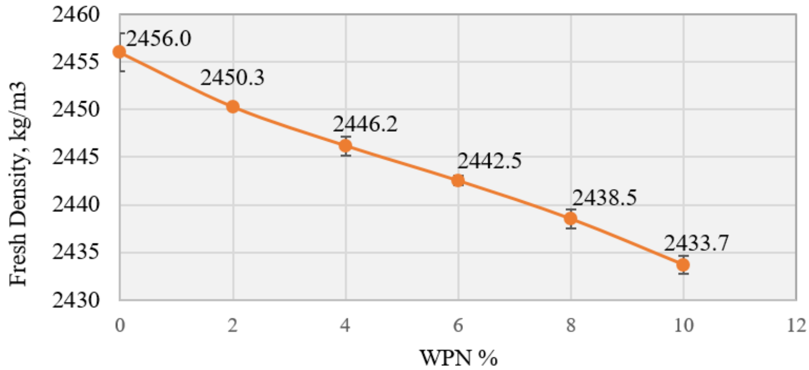


Figure 6. Profile of fresh density values for WPN-concrete mixes

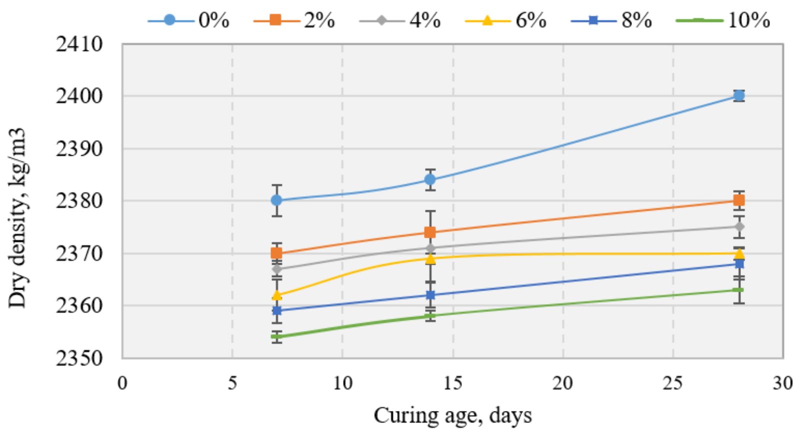


Figure 7. Profiles of dry density for WPN-concrete mixes

3.3. Water absorption

Profiles of water absorption by WPN-concrete mixes are given in Fig. 8. The results demonstrated that the capability of concrete to absorb water increased with increasing the WPN content. In other words, due to the increase in WPN content, there was a tendency for higher water absorption as compared to that of reference concrete. This trend can be attributed to the hydrophobic nature of the waste plastic material portion of the WPN which restricts the movement of water into and within the concrete. Siddique et al. [24] reported that water absorption is dependent upon blend compositions. Ogbu et al. [25] suggested that by increasing the waste plastic content to 1%, a significant increase in concrete water absorption can be observed. Ohemeng and Ekolu [26] stated that the absorption of concrete contained 20% of Low-density polyethylene (LDPE) to replace the sand increased the water absorption by 3.14%. El-Nadoury [27] reported that the water absorption increased by the incorporation of untreated plastic particles in concrete compared to those mixes made with chemically treated plastic. The increase in water absorption was higher than 300% for concrete mixes with 50% untreated plastic granules.

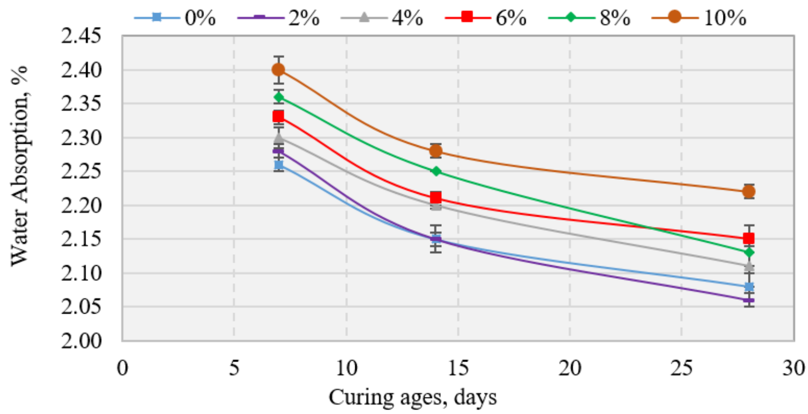


Figure 8. Profiles of water absorption for WPN-concrete mixes

3.4. Compressive strength and flexural strength tests

Fig. 9 shows compressive strength profiles for concrete mixes after 7, 14, and 28 days. It is well observed that the compressive strength of WPN-concrete increased marginally with increasing WPN ratio after 7 curing days. With increasing WPN content, the compressive strength at 14, and 28 curing days decreased. Hence, even the minimum compressive strength value (33.39 MPa) for 10% of aggregate replacement at 7 days of curing age was higher than the minimum acceptable value (17MPa) of lightweight concrete for structural application. This observation can be explained by the WPN's lower density relative to sand, as well as its strength and smooth texture. The slight reduction in strength values could be due to the presence of the polymeric fine granules and particulates led to a reduction in the level of concrete packing (Fig. 10 (a)-(c)). The low strength of bonding between the cement and the polymeric fine particles could be an additional reason for the reduction of strength. Prajapati and Karanjit [28] suggested that there is a major link between aggregate type by source and the overall strength and efficiency of different nominal mix design concrete in both the green fresh stage and the hardened stage. Different aggregate forms have a major effect on concrete compressive strength.

Results of the flexural strength test for WPN-concrete mixes indicated that with increasing WPN ratio, the flexural strength of WPN-concrete mixes decreased at each curing age (Fig.11), with the exception of ratios 2% and 4% which tend to increase higher than the reference concrete mixes at each curing day. This decrease in the flexural strength with the increase in WPN content could be attributed to the stress concentrations induced by the fibroform shaped WPN particles. The decrease may be due to the decrease in the adhesive strength between the surface of the waste plastic particles portion of the WPN and cement in concrete mixes. Rai et al. [29] suggested that the decrease in flexural strength is due to the low resistance of waste materials incorporated in the concrete mixes. A similar trend of decreasing flexural strength were observed by Dashrath et al. [30] for concrete mixes prepared with recycled aggregate. Fadiel et al. [31] showed that the addition of rubber particles to concrete decreased the flexural strength in comparison with control concrete which was justified due to the lack of conventional fine aggregate directly resulted in the loss of flexural strength.

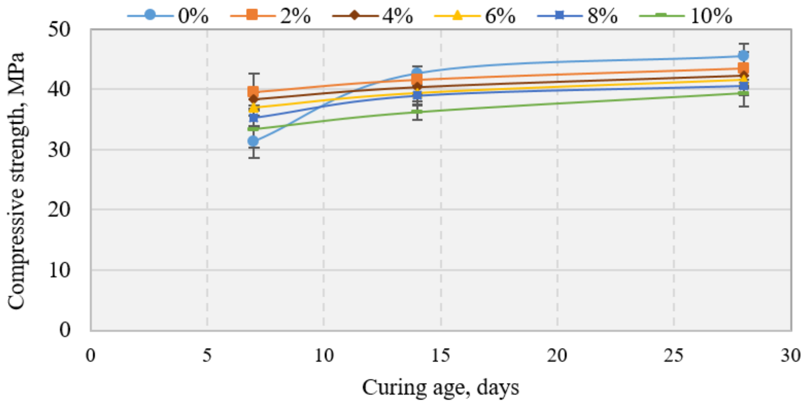


Figure 9. Profiles of compressive strength values for WPN-concrete mixes

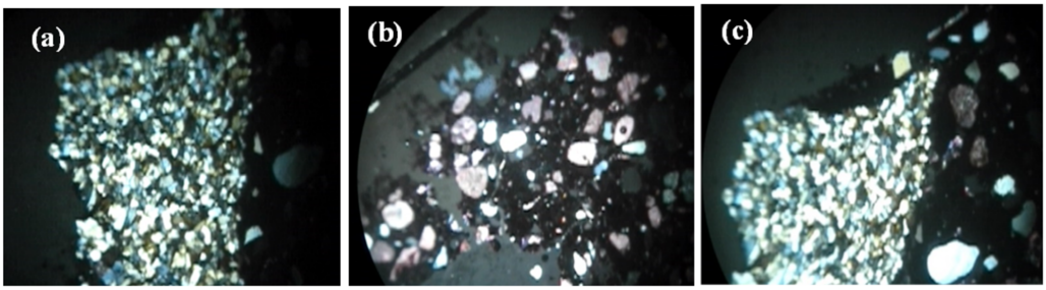


Figure 10. Microstructure for the WPN-concrete mixes

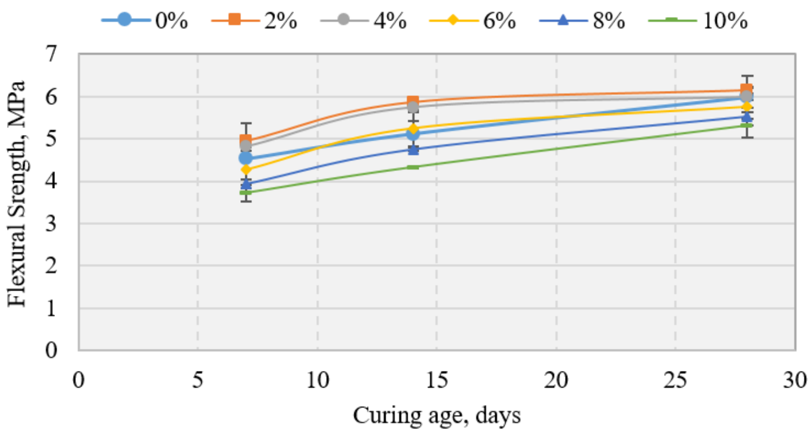


Figure 11. Profiles of flexural strength for WPN-concrete mixes

3.5. Leaching test

From the environmental point of view, the leaching test is considered as the major and most important test for examining the potential of concrete mix to hold back and prevents the movement and leakage of pollutants. In this study, the results of the leaching test indicated the absence of the target components in the leachant as given in Table 7. The absence of these components in the leachant could be due to the assumption that a significant retention of the fibroform particles of the shredded needles or the plastic particulates occurred within the structure of WPN-concrete mixes. However, the very slight change in the concentrations of total dissolved solids (TDS) and $SO_4{}^{-2}$ constituents could be due to dissolution or exudation of the concrete materials, not related to the contents of WPN. The outcomes of the leaching test implied that using WPN is non-hazardous for concrete mixes and could meet the requirements of clean construction products.

Table 7. Quality of the leachant from WPNs-concrete mixes

Constituent	Unit	Concentration			
		Initial (DW)	After 28 days	After 120 days	After 180 days
TDS	mg/L	11 ± 0.5	12 ± 0.9	13 ± 0.2	13 ± 0.6
TSS	mg/L	ND*	ND	ND	ND
Fe^{+2}, Fe^{+3}	mg/L	ND	ND	ND	ND
COD	mg/L	ND	ND	ND	ND
NH_4^+	mg/L	ND	ND	ND	ND
Cl^-	mg/L	≤ 7	≤ 7	≤ 7	≤ 7
SO_4^{-2}	mg/L	≤ 5	≤ 8	≤ 10	≤ 10
pH	-	7	7.8	8.3	8.0
Turbidity	-	Clear	Clear	Clear	Clear
Color	-	Colorless	Colorless	Colorless	Colorless

* ND = not detected

4. Conclusions

This experimental investigation aimed to assess the potential of recycling and incorporating mixed medical solid wastes (WPN) in lightweight concrete mixes. The properties of WPN-concrete mixes were found to be within the acceptable values for lightweight concrete grade M17. The slumps of WPN-concrete specimens decreased with increases in the WPN content, which is believed to be influenced by the WPN irregular grain shapes. In spite of this decline in the slump of these mixtures, they were workable. Using WPN as a partial replacement for fine aggregate did not produce any notable change in the concrete color. By increasing the WPN content in concrete mixes, a decrease in the fresh density and dry density values was observed. Water absorption values of the WPN-concrete mix improved for all curing ages with increasing WPN content.

As the WPN ratio increased, the compressive strength of the concrete blends decreased. However, after 7 days of curing, with the 2% replacement of fine aggregate, the minimum value of compressive strength was higher than the minimum acceptable value for lightweight concrete used for constructional applications. Also, the flexural strength values decreased as the WPN ratio in the concrete mix increased.

Results of leaching test indicated the absence of measurable pollutants in the leachate indicating that from an environmental perspective, using WPN in the concrete mix is a safe and environmentally friendly approach for handling this hazardous waste.

Acknowledgment

The authors would like to express their gratitude to Tikrit University's Department of Civil Engineering for their technical assistance.

References

[1] Kumar, U., Srivastava, V., Singh, A. K. (2016). Suitability of biomedical waste ash in concrete. *International Journal of Engineering and Technical Research*, 5(2):2454–4698.

[2] Deepak, A., Sharma, V., Kumar, D. (2022). Life cycle assessment of biomedical waste management for reduced environmental impacts. *Journal of Cleaner Production*, 349:131376.

[3] Kaur, H., Siddique, R., Rajor, A. (2019). Influence of incinerated biomedical waste ash on the properties of concrete. *Construction and Building Materials*, 226:428–441.

[4] Ababneh, A., Al-Rousan, R., Gharaibeh, W., Abu-Dalo, M. (2019). Recycling of pre-treated medical waste fly ash in mortar mixtures. *Journal of Material Cycles and Waste Management*, 22(1):207–220.

[5] Bamakan, S. M. H., Malekinejad, P., Ziaeian, M. (2022). Towards blockchain-based hospital waste management systems applications and future trends. *Journal of Cleaner Production*, 349:131440.

[6] Kumar, A., Pandey, M. (2017). Reuse of hospital plastic waste in concrete as a partial replacement of coarse aggregate: an overview. *International Research Journal of Engineering and Technology*, 4(8): 1894–1895.

[7] Silva, R. V., de Brito, J., Saikia, N. (2013). Influence of curing conditions on the durability-related performance of concrete made with selected plastic waste aggregates. *Cement and Concrete Composites*, 35(1):23–31.

[8] Khilesh, S. (2014). Study of strength property of concrete using waste plastics and steel fiber. *International Journal of Engineering And Science*, 3(5):9–11.

[9] Verma, S., Arora, S. (2015). Replacement of natural sand in concrete by polyethylene bottles. *International Research Journal of Engineering and Technology (IRJET)*, 2(01):120–124.

[10] Arivalagan, S. (2016). Experimental investigation on partial replacement of waste plastic in concrete. *International Journal of Engineering Sciences & Research Technology*, 5(11):443–449.

[11] Jaivignesh, B., Sofi, A. (2017). Study on Mechanical Properties of Concrete Using Plastic Waste as an Aggregate. *IOP Conference Series: Earth and Environmental Science*, 80:012016.

[12] Shah, S. S. A., Khan, R. (2016). Re-Use of Hospital Plastic Waste in Asphalt Mixes as Partial Replacement of Coarse Aggregate. *Open Journal of Civil Engineering*, 06(03):381–387.

[13] Hamada, L., Ismail, Z. (2021). Sustainable Approach for Recycling Medical Waste Needles to Partially Replace Aggregate in Lightweight Concrete Production. *Advances in Science and Technology Research Journal*, 15(1):166–173.

[14] Ho, L. S., Huynh, T.-P. (2022). Recycled waste medical glass as a fine aggregate replacement in low environmental impact concrete: Effects on long-term strength and durability performance. *Journal of Cleaner Production*, 368:133144.

[15] Neville, A. M. (1996). *Properties of concrete*, volume 4. Longman London.

[16] ASTM C192 (1980). *Standard practice for making and curing concrete test specimens in laboratory*. Annual Book of ASTM Standards, American Society for Testing and Materials.

[17] B.S.1881 (1952). *Methods of testing concrete*. British standards, London.

[18] ASTM C143/C143M-00 (2000). *Standard test method for slump of hydraulic-cement concrete*. Annual Book of ASTM Standards, American Society for Testing and Materials.

[19] ASTM C293 (1979). *Standard test method for flexural strength of concrete (using simple beam with center-point loading)*. Annual Book of ASTM Standards, American Society for Testing and Materials.

[20] ASTM C642 (1997). *Standard test method for density, absorption, and voids in hardened concrete*. Annual Book of ASTM Standards, American Society for Testing and Materials.

[21] JSCE-G 575-2005. *Test Method for Leaching of Trace Elements from Hardened Concrete*. Japan Society of Civil Engineers, Tokyo, Japan.

[22] Ismail, Z. Z., AL-Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. *Waste Management*, 28(11):2041–2047.

[23] Sabale, V., Ghugal, Y. (2014). Experimental Study of Fresh Concrete Properties of Fiber Reinforced Concrete with Metakoalin. *International Journal of Emerging Engineering Research and Technology*, 2 (4):85–95.

[24] Siddique, R., Khatib, J., Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management*, 28(10):1835–1852.

[25] Ogbu, C. A., Sangodoyin, A. Y., Mokhtar, R. (2018). Potentials of increasing levels of recycled waste plastic on the physical characteristics of concrete. *Journal of Civil Engineering and Environmental Sciences*, 4:50–55.

[26] Ohemeng, E. A., Ekolu, S. O. (2019). Strength prediction model for cement mortar made with waste LDPE plastic as fine aggregate. *Journal of Sustainable Cement-Based Materials*, 8(4):228–243.

[27] El-Nadoury, W. W. (2022). Chemically treated plastic replacing fine aggregate in structural concrete. *Frontiers in Materials*, 9.

[28] Prajapati, J., Karanjit, S. (2019). Effect of Coarse Aggregate Sources on the Compressive Strength of Various Grade of Nominal Mixed Concrete. *Journal of Science and Engineering*, 7:52–60.

[29] Rai, B., Rushad, S. T., Kr, B., Duggal, S. K. (2012). Study of Waste Plastic Mix Concrete with Plasticizer. *ISRN Civil Engineering*, 2012:1–5.

[30] Dashrath, K. B., Anil, N. M., Wakchaure, M. R., Kulkarni, V. P. (2014). Effect of aggregate types on flexural strength of concrete. *International Journal of Scientific Engineering and Technology*, 3(7):906–909.

[31] Fadiel, A. A. M., Mohammed, N. S., Abu-Lebdeh, T., Munteanu, I. S., Niculae, E., Petrescu, F. I. T. (2023). A Comprehensive Evaluation of the Mechanical Properties of Rubberized Concrete. *Journal of Composites Science*, 7(3):129.