The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2025

Volume 37, Pages 1114-1123

ICEAT 2025: International Conference on Engineering and Advanced Technology

The Mechanical and Physical Properties of Reactive Powder Concrete Reinforced with Carbon Nanotubes Reinforced with Standard Steel Fiber and Recycled Fiber from Tires

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Abstract: Multi-walled carbon nanotubes (MWCNTs) are a promising material in the field of civil engineering because they have unique properties of high stiffness and strength, light weight, and good thermal conductivity. In this research, two parameters were studied. First one, 0.01% and 0.03% of MWCNTs (Taking as a proportion of the weight of cement) were added to reactive powder concrete. The second parameter was steel reinforcements where standard synthetic steel fiber was added to specified mixes and recycled waste tire wire was added to other mixes), to look into how they affect the mechanical and physical properties of reactive powder concrete (RPC). Cement has been partially replaced by silica fume because it is a key ingredient in RPC. The findings indicated that adding 0.03% carbon nanotubes increased the splitting tensile strength (SS), compressive strength (CS) and flexural strength (FS) by 20.09%,4.85% and 24%, respectively, of the standard steel fiber-reinforced RPC. Using recycled waste tire gives results that are close to those of standard manufactured steel fibers. The adding of 0.03% of MWCNTs and the recycled waste tire wire (RSFT) were improved the mechanical properties of RPC.

Keywords: Reactive powder concrete, Multi-walls carbon nanotubes, Mechanical and physical properties, Recycled waste tire wire

Introduction

One of the most sought-after building materials worldwide is concrete after the development of technology and the continuous construction in countries and the increase in wars, destruction and devastation. However, traditional concrete has restrictions in some construction applications such as shell structures, special structures and structures with long spans. Therefore, many researchers have worked on developing concrete and improving its properties through conducting continuous research to reach the best properties and capabilities for concrete, in addition to reducing its negative effects on the environment, making it more economical, and giving it greater flexibility in handling. Research is still continuing in this field to this day.

RPC is regarded as a new generation of building materials that outperform traditional concrete in terms of durability and mechanical properties. (Abid et al., 2019). Secret of its the material that makes it up. Therefore, it is called powder concrete, and it improves its chemical and physical interaction at the microscopic level (Mayhoub et al., 2021). It consists of a high proportion of cement, silica sand, fine sand, steel fibers, chemical additives, and a very low water/cement ratio, which is a crucial element in determining the properties of this

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concrete (Richard et al., 1995). As a result, this concrete has high durability and high compressive strength ranging from 150 to 800 MPa or more, and excellent resistance to harsh environmental conditions. It was developed by the French scientist Dr. Pierre Richard at Bouygues (Richard et al., 1994; Richard et al., 1995).

Many researchers have introduced nanomaterials such as nano titanium, nano silica, nano iron oxide, and CNT into concrete to obtain satisfactory results due to the development taking place in the field of nanotechnology (You et al., 2017; Yu et al., 2014). Among these nanomaterials, CNT are considered Among promising nanomaterials in the field of construction because to their distinct characteristics, including superior mechanical strength. There are two kinds of carbon nanotubes single-walled carbon nanotubes, multi-walled carbon (MWCNTs). Because of the distinct properties of CNT, researchers have begun to incorporate them into building materials. The impact of the size of MWCNTs on their effect when used as filler for concrete was investigated. It was concluded that when using small-sized carbon nanotubes, it will result in better distribution because they will be spread over a wider range, thereby filling the nano-voids in the cement matrix more effectively. Provide stronger cementitious compounds (Manzur et al., 2014). multi-walled carbon nanotubes fill the pores inside the sample, delay the decline in CS of concrete after multi-generation recycling, and close the cracks (Wu et al., 2024) CNT can reduce the porosity of composites (Zaheer et al., 2020). Using the appropriate type and amount of carbon nanotubes enhances the mechanical properties (FS and CS) of RPC (Ruan et al., 2018). Adding 0.025% carbon nanotubes to reactive powder concrete will increase the FS, CS, and SS at initial cracking, as well as the SS at twenty-eight days of curing.

According to microscopic analysis, the presence of carbon nanotubes slowed down the growth of nano-cracks (Liu et al., 2019). Adding MWCNTs to cementitious composites will reduce porosity and minimize crack propagation at the nanoscale, thereby increasing FS and CS (Li et al., 2021). However, if the proportion of CNT increases to a high percentage, this will lead to a negative effect and a decline in CS, according to studies. It was found that using a ratio of 0.8% multi-walled carbon nanotubes led to a 21% decrease in CS compared to the reference sample without carbon nanotubes. This is due to the difficulty of dispersing a large amount of MWCNTs, which leads to the formation of clumps in cement hydration products. This is due to the difficulty of dispersing a large amount of multi-walled carbon nanotubes, which causes the creation of clumps in cement hydration products. As a result, the pores and voids in the cement matrix will increase, thereby reducing the mechanical properties of the concrete. Therefore, an ideal ratio must be chosen for use (Cui et al., 2017). When Portland cement is reinforced with 0.1% multi-walled carbon nanotubes, we observe an enhancement of the CS by 22% at seven days and 15% at twenty-eight days. in addition to enhance the FS of the cement paste. According to scanning electron microscopy (SEM) analysis, MWCNTs are well spread out in the products that come from cement hydration and bridging and filling the network occurs (Xu et al., 2015). When using high-dispersion multi-walled carbon tubes, it increases the stiffness of C-S-H and minimizes porosity (Konsta-Gdoutos et al., 2010). When adding 0.05% of MWCNTs to cement composites, CS improves by 15%, and FS increases by 1%. When adding 0.15%, CS will improve by 10% and increase FS by 28%, which indicates that different ratios lead to different effects on the mechanical properties of concrete, that is, growing CS by a high percentage does not mean increasing the flexural strength by a high percentage at the same percentage of adding carbon nanotubes (Irshidat et al., 2020). Adding carbon nanotubes to cement pastes reduces their porosity and increases their capacity to seal nanoscale cracks(Zou et al., 2015).In general, when carbon nanotube is added to any matrix and well distributed, we will get many benefits (accelerated cement hydration, stronger and lighter structural composite materials, improved mechanical strength, reduced porosity, water absorption, permeability, increased resistance to freezing and thawing, reduced fire risk, increased electrical conductivity and high thermal conductivity). However, when not properly distributed, it will give limited benefits or negative results (Rashad, 2017).

Therefore, this paper focuses on investigate the effect of MWCNTs on the mechanical properties of RPC containing either standard steel fibers or recycled waste tire wire. Various tests were conducted to see the impact of MWCNTs on CS, SS, FS, and thermal conductivity for reactive powder concrete.

Experimental Program

Materials Properties

This study, high sulfate-resistant cement was used due to its high fineness, this property is useful in improving the properties of RPC and making it denser. It was used by 980 (kg/m³) For all mixtures (Table 1) shows the properties of cement, silica fume by 245 (kg/m³) for all mixtures, fine sand size 600μm by 1050 (kg/m³) for all mixtures, superplasticizer by 3(L/kg) (by weight of binder), Water/binder 0.21. (Table 2) shows the properties of manufactured steel fibers (MSF), and RSFT. (Table 3) shows the properties of MWCNTs. (Table 4) shows the mixing ratios of the materials mentioned in (Tables 1, 2, and 3).

Table1. Chemical properties of high sulfate-resistant cement

Component	SiO_2	Al_2O_3	Fe_2O_3	MgO	Loss
Amount %	22.8	3.32	3.4	2.8	2.86

Table2. Properties of steel fiber

Type	Shape	Diameter mm	Length mm	Density kg/m³	Aspect ratio	Modulus of elasticity (E) MPa	Tensile strength (ft) MPa
Industry steel fiber	Hook ends	0.5	35	7800	70	2×105	≥ 1000
recycled steel fiber	straight	0.28	35 ± 2	7800	125	----------	--------

Table3.Properties of carbon nanotubes

Property	Specification
Chemical composition	Carbon
Brand name	Juyuan
Name of the material	Carbon nanotubes
Diameter	5-11 nm
Average diameter	10 nm
Length	10-50 µm
Density	0.03-0.04 kg/cm³
Purity	90.9%
Type	Mult-wall

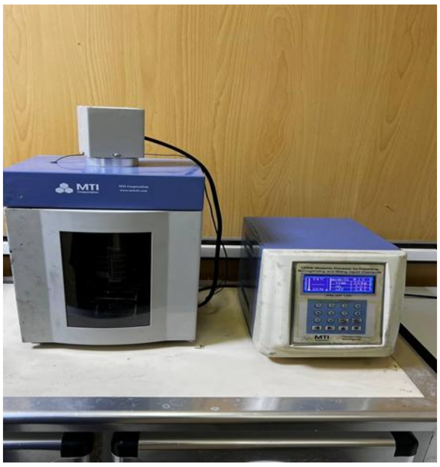
Table4. Proportion of mixing

Type	Name	Standard Steel fiber (by volume)	Recycled steel fiber from tire (by volume)	Carbon nanotubes (by weight of cement)
Reference	1MSF	1.5%	-------------	-------------
	1RSF	------------	1.5%	-----------
	2MSF	1.5%	---------------	0.01%
	3MSF	1.5%	-----------------	0.03%
	2RSF	------------	1.5%	0.01%
	3RSF	------------	1.5%	0.03%

Carbon Nanotube Preparation

Figure1. Carbon nanotubes

(a)



(b)

Figure 2. (a) Magnetic stirrer device (b) Ultrasonic processor for disponing homogenizing and mixing liquid chemical device.

Water was added to the carbon nanotube in specific proportions, and a magnetic cap was placed inside it. It was placed on a magnetic stirrer device for 10 minutes, and then it was transferred to an ultrasonic processor for 20 minutes. After that, the nano solution was obtained. (Figure 1) shows the shape of the carbon nanotube in both the powder and liquid state.

Fabrication of the Specimens

Six concrete mixes were prepared, each series consists of 6 cubes measured 10 cm x 10 cmx 10 cm for CS, 3 cylinders measured (10 x 20 cm) for indirect splitting tensile strength, 3 cylinders measured (2.5 x 12 cm) for thermal conductivity, and 3 prisms measured 10cm x 10cm x 50 cm for FS. A horizontal mixer was used to mix silica fume, cement, and sand together for five minutes. For 10 minutes, continuous mixing was used to gradually add the water, superplasticizer, and carbon nanotubes mixture. Then, steel fibers were added manually. The mixing process took from 25 to 30 minutes, and they were placed in the moulds. After twenty-four hours, after being taken out of the molds, they were heated in water basins with a heater.

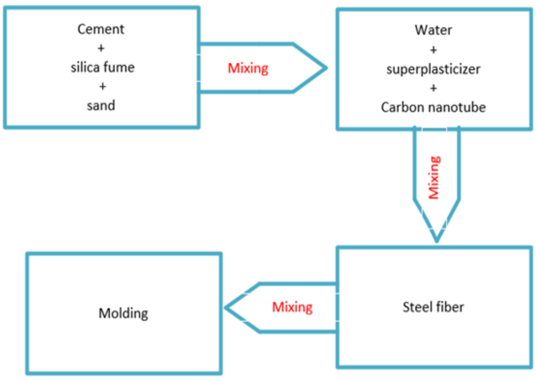


Figure 3. Fabrication process of specimens.

Tests

Density Test

The density calculated by dividing the specimen's mass by its volume. The average of 6 cubes measured (10 x 10 x 10 cm) for each mix was registered.

Compressive Strength Test

This test was performed on six cubes, measured (10 x 10 x 10 cm), after 28 days of curing complied with the BS 1881-116:1983 specification. (Testing concrete, 1983).

Splitting Tensile Strength Test

SS test was carried out after 28 days, and the average of 3 cylinders measured (10 x 20 cm) was calculated. This test was conducted according to the ASTM C 496/C 496M – 04e1 specification.

Flexural Strength Test

3 prisms measuring (10 x 10 x 50 cm) were conducted to investigate the FS by the three-point bending test. According to the ASTM C 78 – 02 specification.

Thermal Conductivity Test

Concrete's ability to conduct heat is measured in W/M. K according to the ASTM C177 through its thermal conductivity coefficient (K). The KD2Pro device was used to measure this coefficient. As stated in the specifications KD2Pro device, a cylindrical sample with a diameter of 25 mm and a length of 120 mm has an internal hole of 2.4 mm in diameter and a length of 100 mm was used.

Results and Discussion

Density Test

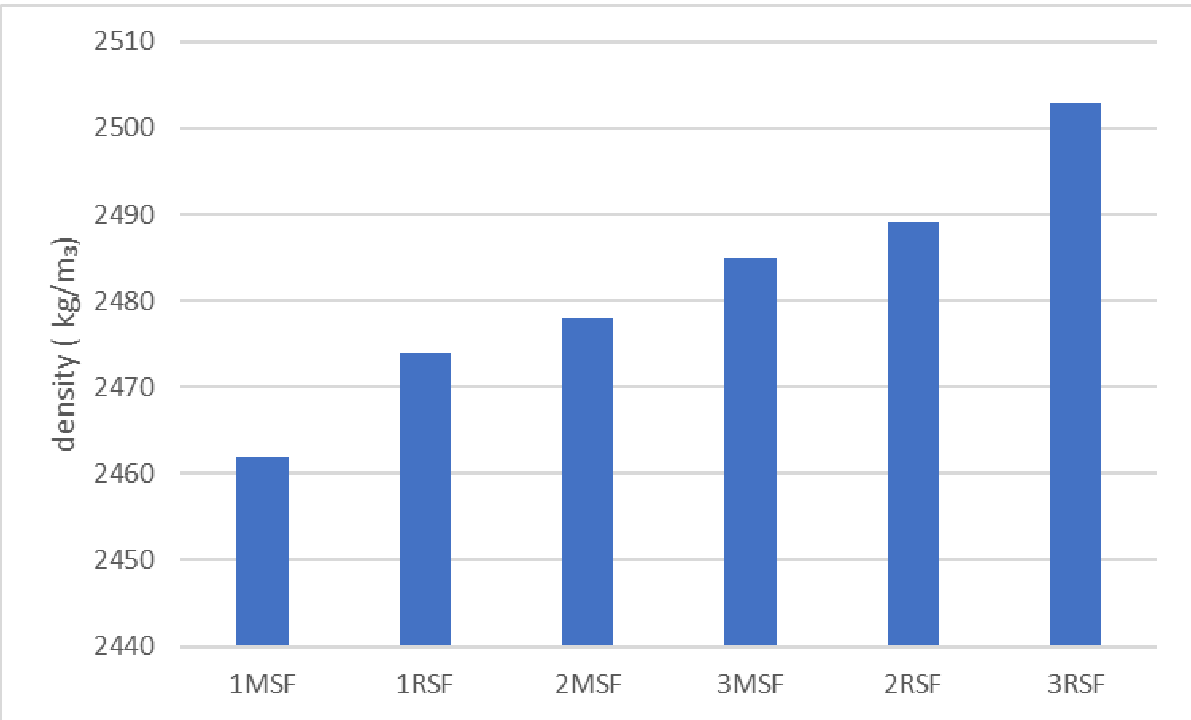


Figure 4. Density test result

The density of the mixes containing standards steel fiber, results for all mixes were between 2462 and 2503 kg/m^3, as depicted in (Figure 4). The density of the reference mix 1MSF was 2462. The density increased by 0.64% when the 2MSF mix was enriched with 0.01% multi-walled carbon nanotubes. Moreover, when adding 0.03% carbon nanotubes to the 3MSF mix resulted in an increase of 0.93% compared to the 1MSF mix. In the other hand, the mixes which containing recycled waste tire wire RSF, the density 2474 kg/m3. For the 1RSF mixture, its density was 2474 kg/m^3, and the increase in density occurred due to the difference in the quality of steel fibers used in this mixture compared to MSF. When comparing the 2RSF mix, which contains 0.01% carbon nanotubes, there was an increase in density of 0.6% compared to the reference mixture 1RSF. Moreover, when adding 0.03% carbon nanotubes to the 3RSF mix, there was an increase in density of 1.17% when compared to the reference mixture 1RSF. Adding MWCNTs to RPC, whether reinforced with manufactured steel fibers or steel fibers recycled from tires will increase the density (Zaheer et al., 2020). The increased density of reactive powder concrete containing CNT is led to the fact that Carbon Nanotubes act as nanofiller within the concrete's voids and nanopores. In addition, they work to form a C-S-H Gel and enhance hydration. (Jing et al., 2024; Naqi et al., 2019).

Compressive Strength Test

The results of all CS mixtures range from 79.8 to 83.88 MPa, as shown in (Figure 5). The percentage of MWCNTs and the types of steel fibers had a noteworthy impact on CS. When comparing the control mix 1 MSF with the mix 2 MSF which includes 0.01% carbon nanotubes, a growth of 1.7% in CS was observed in mix 2 MSF. When higher percentage (0.03%) of carbon nanotubes was added, the increase in compressive strength reached 4.85%. For the second mix, RSF, when 0.01% of carbon nanotubes were added, the compressive strength increased by 1.37%, and when 0.03% of carbon nanotubes were added, it increased by 3.38%. This means that increasing the percentage of MWCNTs leads to a rise in CS. When properly dispersed, nanomaterials form bridges across micro and macro cracks and redistribute the internal stresses. These bridges prevent the expansion and propagation of cracks, thus increasing the resistance of concrete to compression and transferring the internal stresses more efficiently (Cui et al., 2017).

Splitting Tensile Strength Test

The results of all SS mixtures range from 9.5 to 12.13 MPa, as shown in (Figure 6). When comparing the control mix 1 MSF with the mix 2 MSF where 0.01% of carbon nanotubes was added there was a rise of 10% in ss of mix 2 MSF. As well, when a higher percentage of carbon nanotubes (0.03%) was added, the rise in ss was 20.09%. For the second mix (RSF), when 0.01% of carbon nanotubes was added, SS rise by 17.8%, and when 0.03% of carbon nanotubes, it increased by 25.26%. These results revealed that SS of concrete can be improved by adding MWCNTs. It improved the bonding of concrete components and redistributed the internal stresses on the concrete surface uniformly across the crack patterns (Wang et al., 2022).

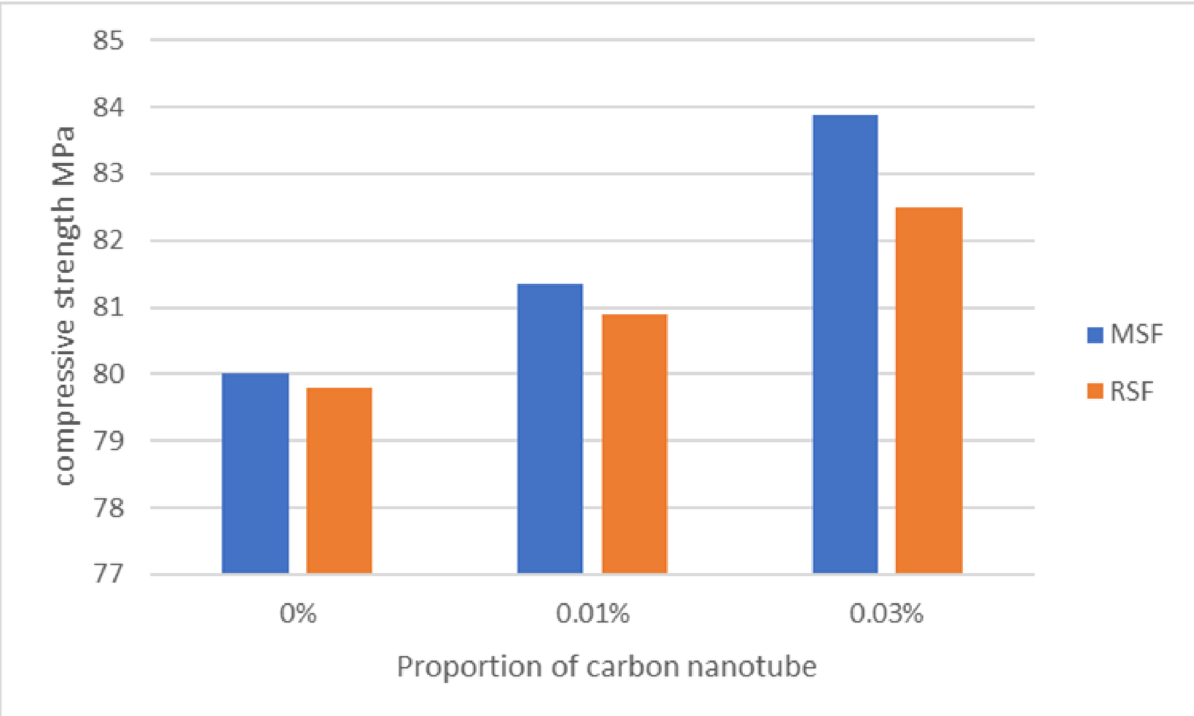


Figure 5. CS test result

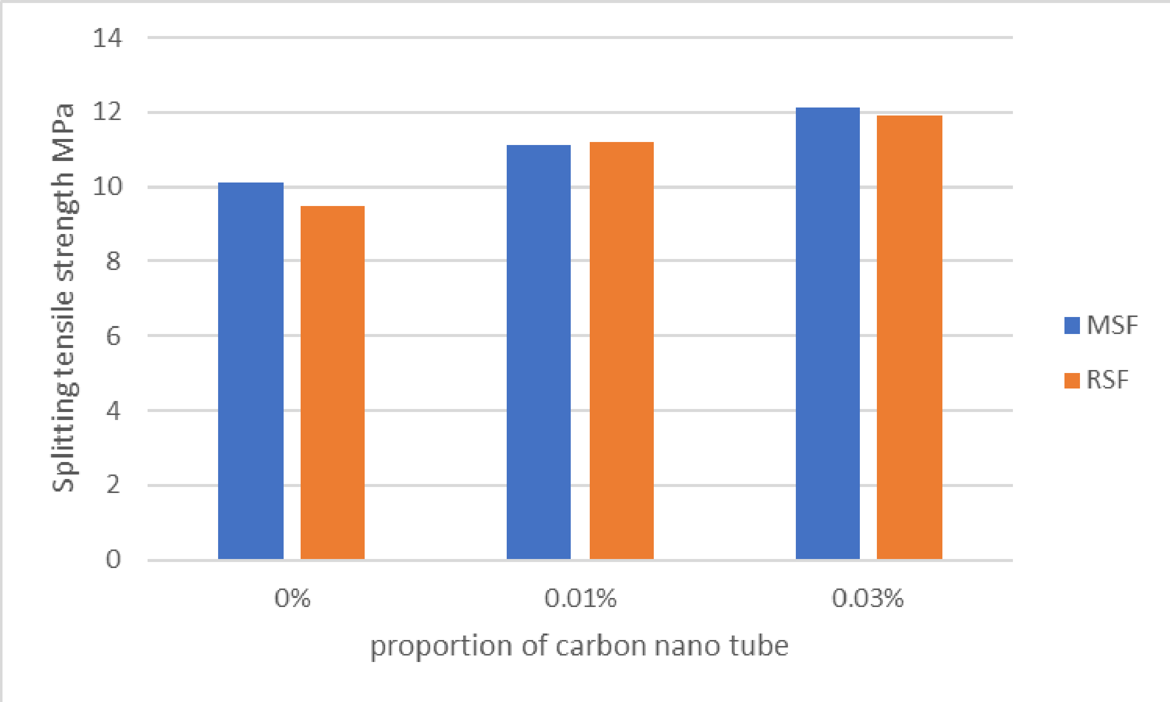


Figure 6. SS test result

Flexural Strength Test

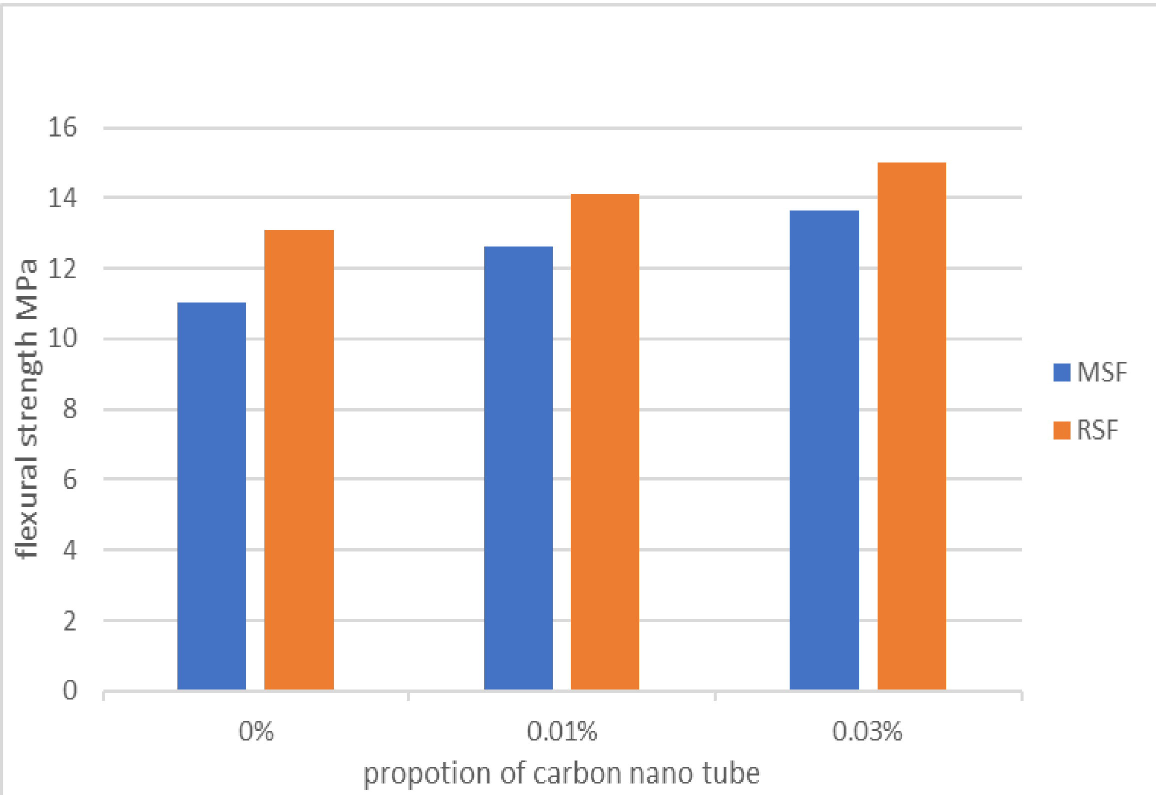


Figure 7. Flexural strength test result

The results of all FS mixtures range from 11 to 15 MPa, as shown in (Figure 7). FS was influenced by multi-walled carbon nanotubes and other steel fibers. There was a rise of 14.5% in FS when 0.01% of carbon nanotubes were added compared to the control mix of 1MSF. When a higher percentage of carbon nanotubes (0.03%) was added, the rise in FS was 24.09%. The second mix (RSF) follows the same tendency. Adding

0.01% of carbon results in a 7.6% increase in flexural strength, while adding 0.03% of carbon nanotubes results in a 14.5% rise in FS. FS will increase as the amount of carbon nanotube added increases. Carbon nanotube enhances the microstructure by filling voids that lead to the reduction of internal structural defects. These voids can be a weak point from which cracks begin to propagate when subjected to flexural forces.

Thermal Conductivity Test

The results of all thermal conductivity mixtures range from 1.38 to 1.86 MPa, as shown in (Figure 8). Thermal conductivity was affected by adding multi-walled carbon nanotubes and changing types of steel fibers. An increase of 8.97% in thermal conductivity was observed when 0.01% of carbon nanotubes was added was added (mix 2MSF). Adding a higher percentage of carbon nanotubes (0.03%) resulted in an increase of 19.23% in thermal conductivity. The increase in carbon nanotubes resulted in an increase in thermal conductivity. The second mix, RSF, follows the same tendency. Adding 0.01% carbon nanotube will increase the thermal conductivity by 8.6% for 2RSF and adding 0.03% carbon nanotube will increase the thermal conductivity by 21.73% for 3RSF. Specimens with standard steel fiber (MSF) have greater thermal conductivity coefficient than the specimen with recycled waste tire wire (RSF). This can be explained by the fact that the Standard steel fibers have a smaller diameter, so for the same volume fraction there will be a larger total surface area of the fibers, resulting in a more interconnected and wider network of steel paths with higher conductivity.

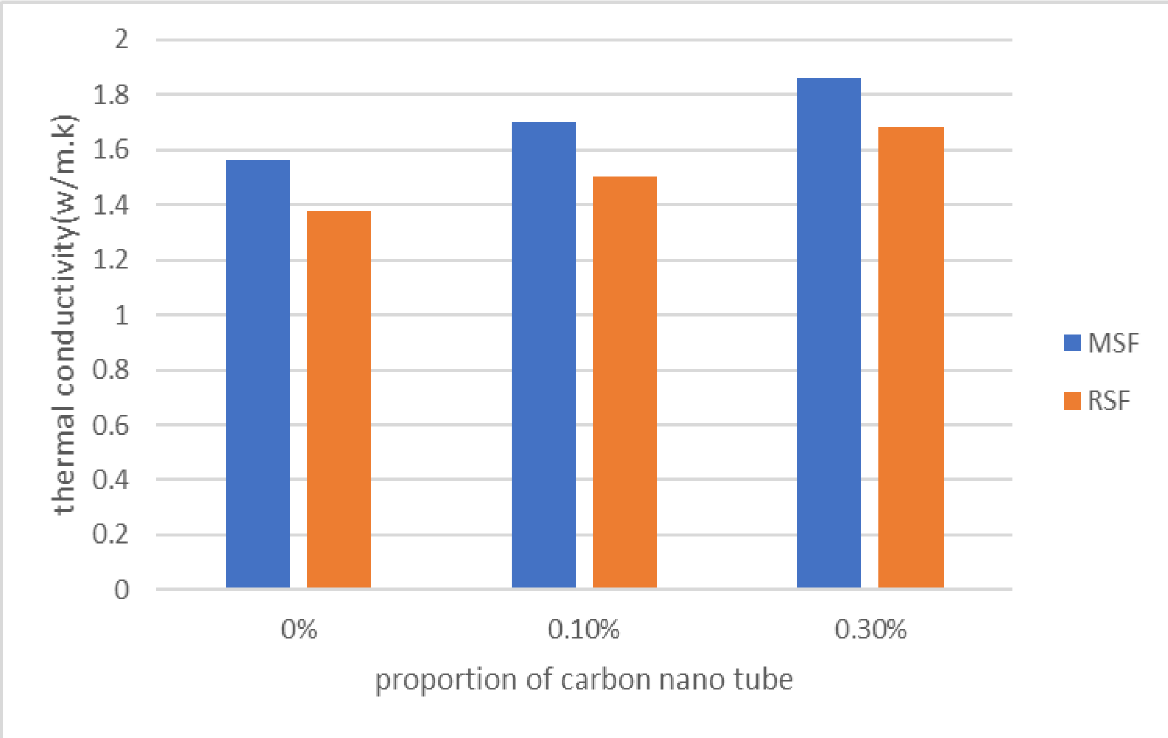


Figure 8. Thermal conductivity test result

Conclusion

In this study, the effect of MWCNTs on RPC was investigated. As well as the effect of RSFT and MSF on the mechanical properties of RPC. The following was concluded:

- Adding 0.01% and 0.03% MWCNTs to RPC Whether reinforced with MSF or RSFT increased the CS, SS, FS, density, and thermal conductivity.
- The use of RSFT improved the mechanical properties of RPC and when compared to MSF, gave close results.
- When RSFT were used, they gave higher results for FS than MSF.
- sing 0.03% MWCNTs gives the best results for improving the mechanical and physical properties of RPC, whether it is reinforced with MSF reinforcement or RSFT.

Recommendations

Using different ratios of CNT to determine their effect. Using different ratios of both types of steel fibers to determine their effect as well.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Engineering and Advanced Technology (ICEAT) held in Selangor, Malaysia on July 23-24, 2025.

References

Abid, M., Hou, X., Zheng, W., & Hussain, R. R. (2019). Effect of fibers on high-temperature mechanical behavior and microstructure of reactive powder concrete. *Materials*, *12*(2), 329.

Cui, X., Han, B., Zheng, Q., Yu, X., Dong, S., Zhang, L., & Ou, J. (2017). Mechanical properties and reinforcing mechanisms of cementitious composites with different types of multiwalled carbon nanotubes. *Composites Part A: Applied Science and Manufacturing*, *103*, 131-150.

Irshidat, M. R., Al-Nuaimi, N., Salim, S., & Rabie, M. (2020). Carbon nanotubes dosage optimization for strength enhancement of cementitious composites. *Procedia Manufacturing*, *44*, 366–370.

Jing, Y., Lee, J. C., Moon, W. C., Ng, J. L., Yew, M. K., & Chu, M. Y. (2024). Mechanical properties, permeability and microstructural characterisation of rice husk ash sustainable concrete with the addition of carbon nanotubes. *Heliyon*, *10*(12), e32780.

Konsta-Gdoutos, M. S., Metaxa, Z. S., & Shah, S. P. (2010). Multi-scale mechanical and fracture characteristics and early-age strain capacity of high performance carbon nanotube/cement nanocomposites. *Cement and Concrete Composites*, *32*(2), 110–115.

Li, S., Zhang, Y., & Du, S. (2021). Mechanical properties and microstructure of reactive powder concrete with multi-walled carbon nanotubes. *Proceedings of SPIE*, *12197*.

Liu, J., Jin, H., Zhao, X., & Wang, C. (2019). Effect of multi-walled carbon nanotubes on improving the toughness of reactive powder concrete. *Materials*, *12*(16), 2625.

Manzur, T., Yazdani, N., & Emon, M. A. B. (2014). Effect of carbon nanotube size on compressive strengths of nanotube reinforced cementitious composites. *Journal of Materials*, *2014*, 1–8.

Mayhoub, O. A., Nasr, E. S. A. R., Ali, Y. A., & Kohail, M. (2021). The influence of ingredients on the properties of reactive powder concrete: A review. *Ain Shams Engineering Journal*, *12*(1), 145–158.

Naqi, A., Abbas, N., Zahra, N., Hussain, A., & Shabbir, S. Q. (2019). Effect of multi-walled carbon nanotubes (MWCNTs) on the strength development of cementitious materials. *Journal of Materials Research and Technology*, *8*(1), 1203–1211.

Richard, P., & Cheyrezy, M. (1995). Composition of reactive powder concretes. *Cement and Concrete Research*, *25*(7), 1501-1511.

Richard, P., & Cheyrezy, M. H. (1994). Reactive powder concretes with high ductility and 200-800 MPa compressive strength. *Special Publication*, *144*, 507–518.

Ruan, Y., Han, B., Yu, X., Zhang, W., & Wang, D. (2018). Carbon nanotubes reinforced reactive powder concrete. *Composites Part A: Applied Science and Manufacturing, 112,* 371-382.

Wang, J., Dong, S., Pang, S. D., Zhou, C., & Han, B. (2022). Pore structure characteristics of concrete composites with surface-modified carbon nanotubes. *Cement and Concrete Composites*, *128*, 104453.

Wu, H., Liu, X., Ma, X., & Liu, G. (2024). Effects of multi-walled carbon nanotubes and recycled fine aggregates on the multi-generational cycle properties of reactive powder concrete. *Sustainability*, *16*(5), 2084.

Xu, S., Liu, J., & Li, Q. (2015). Mechanical properties and microstructure of multi-walled carbon nanotube-reinforced cement paste. *Construction and Building Materials*, *76*, 16–23.

You, I., Yoo, D. Y., Kim, S., Kim, M. J., & Zi, G. (2017). Electrical and self-sensing properties of ultra-high-performance fiber-reinforced concrete with carbon nanotubes. *Sensors*, *17*(11), 2481.

Yu, R., Tang, P., Spiesz, P., & Brouwers, H. J. H. (2014). A study of multiple effects of nano-silica and hybrid fibres on the properties of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) incorporating waste bottom ash (WBA). *Construction and Building Materials*, *60*, 98–110.

Zaheer, M. M., Jafri, M. S., & Varisha. (2020). Multi-walled carbon nano-tubes for enhancing the performance of cementitious composites. *Journal of Physics: Conference Series*, *1706*(1), 012131.

Zou, B., Chen, S. J., Korayem, A. H., Collins, F., Wang, C. M., & Duan, W. H. (2015). Effect of ultrasonication energy on engineering properties of carbon nanotube reinforced cement pastes. *Carbon*, *85*, 212–220.

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To cite this article:

Asmail, S. T., Almusawi, A. M., & Shallal, M.A. (2025). The mechanical and physical properties of reactive powder concrete reinforced with carbon nanotubes reinforced with standard steel fiber and recycled fiber from tires. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 37,* 1114-1123.