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Mechanical and thermal properties of rubberized concrete incorporated silica fume

Othman Hameed Zinkaah[a], Zainab Alridha[a], Musab Alhawat[b] and Amir Khan[b]

[a] Department of Civil Engineering, Al-Muthanna University, Al-Muthanna, Iraq
[b] Faculty of Engineering and Digital Technologies, University of Bradford, Bradford, UK
**Corresponding author E-mail: Othman.h.zinkaah@mu.edu.iq*

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Abstract

Rubberised concrete provides elasticity, energy absorption, lightweight, and excellent acoustic and thermal insulation. Nevertheless, a notable drawback is its reduced compressive strength. To address this, incorporating silica fume emerges as a promising method to enhance compressive strength and overall performance. The current study aims at optimising the mechanical and thermal characteristics of rubberised concrete by incorporating silica fume as an additive. The investigation focuses on identifying the optimal ratio of crumb rubber and silica fume that yields favourable results across various properties, with a particular emphasis on compressive strength and thermal conductivity. Nine concrete mixes were developed, wherein 10% and 20% of the fine aggregate were substituted with two different percentages of crumb rubber. In addition, silica fume was used to substitute 10% and 15% of the cement. The experimental phase involved conducting tests for both compressive strength and thermal conductivity.

The findings indicated a progressive decline in compressive strength as the crumb rubber content increased. This trend, however, was counterbalanced by the strengthening influence of silica fume. The density exhibited a decline with higher rubber content, but a marginal increase was observed upon the inclusion of silica fume. Moreover, water absorption tests indicated heightened absorption in the presence of rubber, countered using silica fume. Furthermore, as rubber content increased, thermal conductivity decreased, enhancing the insulating properties of rubberised concrete compared to plain concrete. Silica fume, while slightly diminishing thermal insulation in non-rubberized concrete, exhibited a negligible impact on the insulation qualities of rubberized concrete. Overall, the concrete mix comprising 20% rubber and 10% silica fume demonstrated the best performance in terms of both compressive strength and thermal conductivity. This research provides valuable insights into optimising the properties of rubberised concrete, offering a compelling pathway for sustainable construction practices with enhanced characteristics.

Keywords: *Rubberised Concrete, Silica Fume, Compressive Strength, Thermal conductivity.*

1. Introduction

End-of-life tyres (ELTs), often referred to as waste tyres, are deemed no longer effective or safe for their initial purpose and are subsequently subjected to direct disposal [1,2,3]. Globally, the quantity of ELTs has experienced a significant increase due to rapid modernisation and the accelerated growth of the automotive sector. The disposal of ELTs raises substantial environmental concerns, stemming from the annual discarding of millions of tires worldwide. Every year, it is estimated that millions of tyres reach the end of their operational lifespan, with the majority ultimately finding their way to landfills or stockpiles. The environmental impact is further compounded by the ongoing expansion of tire production, resulting in the annual production of 1.6 billion tonnes of tires worldwide. Unfortunately, it does not seem that this issue will be resolved anytime soon, given the continued growth in tire production [4,5,6,7]. Disposing of tires through burning and stockpiling in landfills represents the most common and straightforward method. However, such inadequate waste tire management poses significant environmental threats because tyres are non-biodegradable. The rubber present in waste tyres contains harmful and soluble components that can lead to contamination of soil, water, and air. Furthermore, maintaining tire stockpiles creates a substantial risk of fires and offers breeding grounds for mosquitoes, snakes, and rodents. Acknowledging the hazards linked to tyres, the United States Congress passed legislation in 1991, requiring the incorporation of a certain amount of recycled tyres in projects financed by the federal government. Despite the European Union (EU) officially prohibiting tire disposal in landfills since July 16, 2003, the World Business Council for Sustainable Development (WBCSD) highlights that many countries still resort to landfills [8,9]. According to The European Tyre

Recycling Association (ETRA), in Europe, 49% of tyres are directed toward energy recycling, 46% undergo recycling processes, and a mere 5% find their way to landfills. Consequently, there is a pressing need to emphasize tire recycling and repurposing efforts. Tire recycling not only contributes to economic growth by serving as a source of raw materials but also provides a source of income for those collecting used tyres [3,10].

With the rise of the sustainability paradigm across various industries, including construction, the utilization of waste materials has gained traction as a sustainable approach in the construction sector. Numerous research has examined the integration of various waste materials as supplementary additives in cement-based formulations. In the ongoing exploration of sustainable alternatives for waste tyre disposal, these investigations have specifically focused on seamlessly incorporating tyres into diverse construction materials. The pioneering development of rubberised concrete in the early 1990s by Eldin and Senouci marked a significant milestone in this endeavour. The innovative concept involves the incorporation of recycled tyre rubber into concrete mixtures, acting as either a partial or full alternative for aggregates (both fine and coarse), as well as serving as a partial substitute for binders [11].

Tyres consist of approximately 70–80% rubber, complemented by fibres like nylon, polyester, cellulose and steel wires used for reinforcing tyres. Consequently, the primary challenge in the recycling of waste tyres revolves around the separation of rubber from fibres and steel wires [3,12]. Following this, the subsequent stages involve shredding, cutting, grinding, and classifying the recycled rubber through sieving into three main categories: ground, crumb and shredded rubber. Ground rubber, characterized by particle sizes ranging from 0.075 to 0.475 mm, can be utilised as a partial alternative to cement. Crumb rubber, falling within particle sizes from 0.425 to 4.75 mm, acts as fine aggregate substitute. Shredded rubber, with particle sizes exceeding 4.75mm, can serve as a substitute for coarse aggregate [13,14, 15,16,17].

The existing body of research on rubberised concrete has predominantly concentrated on examining the effect of rubber on compressive strength, a critical indicator of concrete quality. Numerous studies consistently demonstrate a significant decrease in compressive strength with an increase in rubber content, particularly exceeding 5% of the mix's total volume [16]. Research suggests that using aggregates with a rubber content exceeding 20% is not viable as a result of a considerable reduction in compressive strength [18,19]. However, according to a study by [20], when crumb rubber replaces fine aggregates up to 3.5%, there is no noticeable decline in compressive strength. Moreover, the influence of rubber on compressive strength fluctuates depending on the rubber content, with higher percentages leading to significant reductions. Various studies highlight a detrimental effect on compressive strength as rubber content increases, emphasising the need for careful consideration in the formulation of rubberised concrete mixes [15,21]. According to [22], The compressive strength experiences an approximately 70% decrease when the rubber replacement level is raised fto 50% of the total volume of the mix, compared to the control mix.

Various factors can result in a drop in the compressive strength of rubberised concrete. Substituting rubber for natural aggregates decreases compressive strength due to rubber's lower modulus of elasticity and density. Rubber tends to rise during casting, forming weaker upper layers. Smooth rubber surfaces result in weak adhesion, leading to cracks and rapid collapse. Hydrophobic rubber captures air bubbles, reducing concrete strength. Rubber-to-rubber connections in high-rubber mixes inefficiently transfer stress, contributing to premature deterioration, as indicated by multiple studies [11,14,15,16,22,23].

Silica fume, a potent supplementary cementitious material, significantly enhances concrete quality, especially compressive strength, as per AASHTO M 307 and ASTM C 1240 standards. Its strong pozzolanic reactivity improves mix homogeneity, reduces porosity, and strengthens the interface between cement and aggregates, leading to a more homogeneous microstructure. During cement hydration, silica fumes undergo a reaction with calcium hydroxide, resulting in the formation of calcium silicate. This process helps close pores and reduce the porosity in concrete matrix. Literature studies have consistently affirmed a significant enhancement in compressive strength with the addition of silica fume to the mixtures, ranging from 12% to 100%, depending on factors like silica fume content and concrete type [15,24,25, 26]. Despite delayed response and dilution effects, silica fume consistently enhances compressive strength, making it a valuable addition to concrete mixes.

The primary target of the current investigation is to evaluate the mechanical and thermal characteristics of rubberised concrete modified with silica fume. To achieve this goal, a systematic experimental approach is employed, involving the preparation of rubberized concrete specimens with various proportions of rubber and silica fume contents. Standard testing procedures are carried out to assess the essential properties (i.e., compressive strength, water absorption and density), while thermal characterization is assessed by measuring thermal conductivity. By addressing the dual challenges of waste tire disposal and the demand for high-performance concrete, the outcomes of this study are anticipated to make a substantial contribution to sustainable and innovative practices in the construction industry.

2. Experimental programme

2.1. Materials

The concrete mixes were designed using Hanson Multicem, a Portland limestone cement with a cement strength of 32.5 MPa. This cement includes an additive promoting air entrainment, enhancing the durability and workability of the concrete, which was a critical consideration in the mix designs. Hanson Multicem adheres to recognized industry standards (i.e., EN 197-1:2011), ensuring the reliability of the research outcomes. This study utilized fine aggregates characterised by particle sizes that passed through a 4.75 mm sieve and retained on a 0.075 mm sieve. The coarse aggregate in the mixture comprised crushed limestone, had a maximum particle size of 10 mm. The density of coarse and fine aggregates was 1600 kg/m^3 and 1650 kg/m^3, respectively. Both fine and coarse aggregates were air-dried in the laboratory in a saturated surfacedry (SSD) state to ensure that the moisture level of the aggregates does not negatively impact the water-to-cement ratio necessary to achieve desirable workability and mechanical properties.

Fig.1 illustrates the sieve analysis of coarse and fine aggregates employed in this study. The particle distribution of both coarse and fine aggregates conforms to the prescribed limits defined by ASTM/C33M [27], as depicted in the figure. MasterGlenium 315C by BASF, adhering to EN 934 part 2 standards, was utilised in this study. It is an ingredient that significantly increases cement dispersion's effectiveness and has a special mode of action. The significant water reduction and exceptional flexibility of MasterGlenium 315C improve the workability of concrete mixtures.

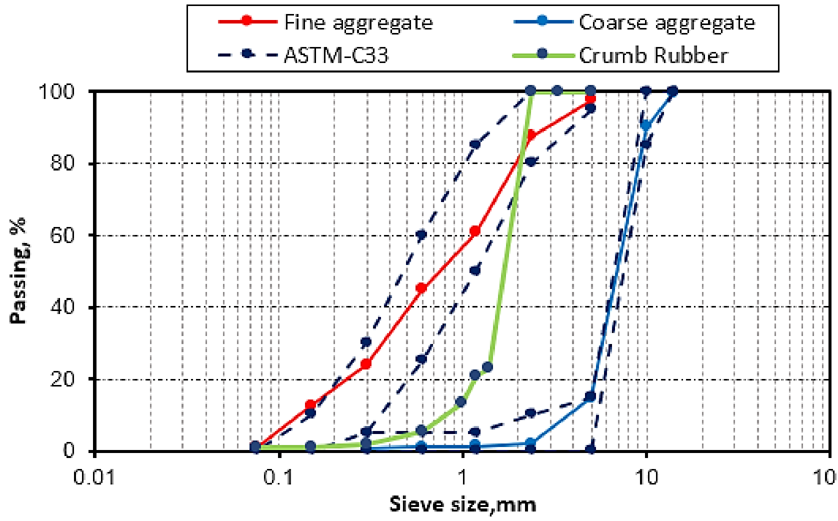
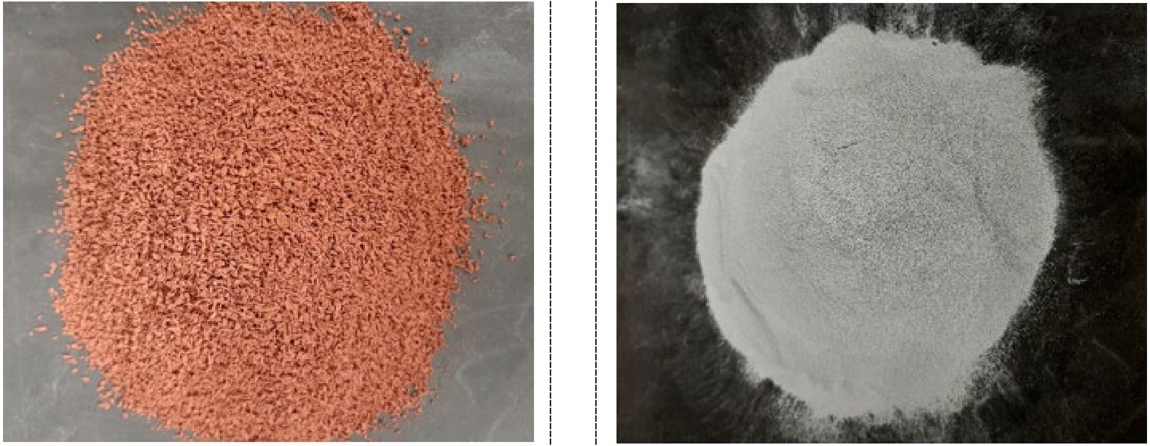


Fig. 1: The distribution of particle sizes in the raw materials.

In this study, the rubber aggregate, sourced from recycled scrap tires, possesses a density of 725 kg/m³, as depicted in Fig. 2. a, illustrating the particle size distribution of the crumb rubber used. The utilised densified silica fume SF90D, characterised by a bulk density ranging from 600 to 750 kg/m³, with 95% of particles measuring less than 45 microns. Fig. 2. b shows the silica fume, while Table 1 illustrates its chemical composition.



a. Crumb rubber

b. Silica fume

Fig. 2: Crumb rubber and Silica fume utulised in the investigations.

Table 1: Chemical composition of SF90D

Chemical composition	Percentage %
Silicon dioxide – SiO_2	92.85
Aluminum oxide – $Al_2 O_3$	0.27
Iron oxide - Fe_2O_3	0.092
Calcium oxide - CaO	0.08
Magnesium oxide - MgO	0.38
Carbon - C	0.8
Sodium oxide – $Na_2 O$	0.17
Potassium oxide – K2 O	0.52
H_2O	0.50
Phosphorus pentoxide - P_2O_5	0.06
Titanium dioxide - TiO_2	0.08
Loss in ignition	4.2

2.2. Mix Proportions

To assess the effectiveness of rubberized concrete modified with silica fume, nine distinct concrete blends were prepared. Crumb rubber was employed to volumetrically replace the fine aggregate, with rubber percentages of 10% and 20% to ensure accurate substitution while accounting for variations in material density, the volume of fine aggregate was converted to the corresponding weight of rubber. In addition, two weight percentages of silica fume (10% and 15%) were employed instead of cement. Three groups, each consisting of three mixes, were established from the nine mixtures. The first three mixtures were formulated to evaluate the influence of crumb rubber proportion without silica fume, incorporating a control mix (0R-0SF). The second set (mixtures 4-6) investigated the effects of replacing 10% of Portland cement with silica fume (by weight), maintaining rubber content. The third set (mixtures 7-9) incorporated 15% silica fume while keeping rubber proportions constant, similar to groups 1 and 2. A consistent water-to-cement ratio (w/c) of 0.45 was maintained across all mixtures. For those containing silica fume, a superplasticizer (0.4% from cementitious components) was employed. Table 2 outlines the ingredients and mixing ratios, with the notation indicating rubber and silica fume proportions.

3. Experimental Methods

The compressive strength at 7 and 28 days was determined by calculating the average results obtained from testing three 100 mm cubes for each respective age group. A total of 54 cube samples, with 6 samples tested for each of the 9 mixtures, were evaluated. Compressive strength tests were conducted using the apparatus illustrated in Fig.3, following the guidelines outlined in BS EN 12390 section 3 [28].

Table 2: Concrete mixtures proportions.

Mix No	Mix ID	Rubber*		Cement (Kg/m^3)	Silica fume**		Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (Kg/m^3)	W/C	Super-plasticizer (Kg/m^3)
		(%)	(Kg/m^3)		(%)	(Kg/m^3)					
1	0R-0SF	0	0	500	0	0	675	732	225	0.45	0.0
2	10R-0SF	10	27	500	0	0	648	732	225	0.45	0.0
3	20R-0SF	20	54	500	0	0	621	732	225	0.45	0.0
4	0R-10SF	0	0	450	10	50	675	732	225	0.45	2.0
5	10R-10SF	10	27	450	10	50	648	732	225	0.45	2.0
6	20R-10SF	20	54	450	10	50	621	732	225	0.45	2.0
7	0R-15SF	0	0	425	15	75	675	732	225	0.45	2.0
8	10R-15SF	10	27	425	15	75	648	732	225	0.45	2.0
9	20R-15SF	20	54	425	15	75	621	732	225	0.45	2.0

* Replacement by volume from the fine aggregate
** Replacement by weight from the cementitious material

Fig. 3: The compressive strength test apparatus.

In terms of thermal conductivity, nine concrete mixes were measured by the apparatus shown in Fig.4, using following procedures: each sample was placed between two boundaries, with one side is subjected to heating from a heat source, while the other side experienced cooling. The test persisted until a stable state of heat flow was reached, and insulation was applied to prevent heat loss. Heat travelled through the sample's unit length, indicating thermal conductivity, with a temperature change of one unit [29,30]. Fig. 5 illustrates a schematic diagram of the thermal conductivity apparatus comprising six aluminium discs (A, B, C, E, F, G) used for measuring thermal conductivity. The concrete sample was placed between discs C and E to align temperatures with the heat variance produced by the heater below disc A. Water was used to cool the three upper discs (E, F, G). Each disc had a temperature sensor to measure variations, with temperatures tracked until they stabilized, signifying a thermal equilibrium state. The test, taking nearly two hours to reach a steady state, provided three parameters: sample thickness, steady-state temperature, and heat source temperature. Equation 3.1 was applied for thermal conductivity calculation.

$$k = \frac{HF\frac{t}{A}}{dT} \qquad (1)$$

where HF represents the heat flux, t denotes the thickness of samples, A signifies the area, dT indicates the temperature difference between the plate above the specimen and the one below.

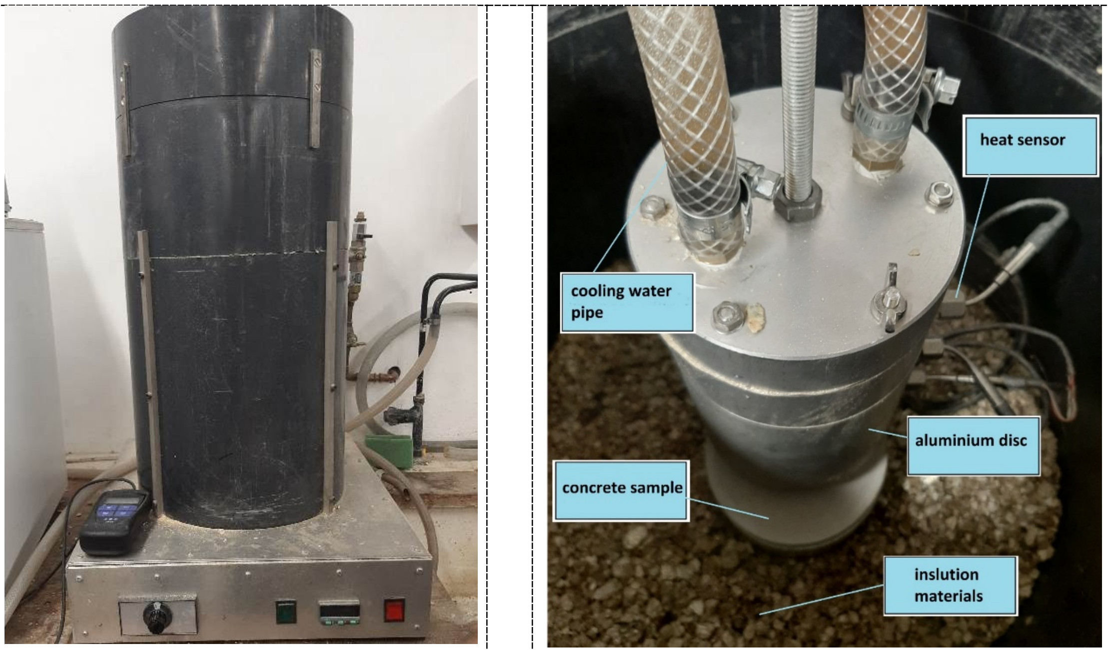


Fig. 4: Thermal conductivity apparatus.

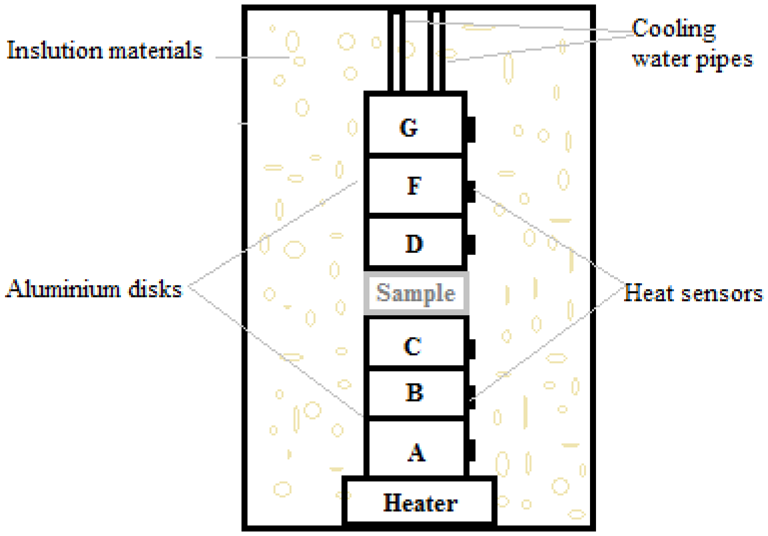


Fig. 5: Schematic diagram of thermal conductivity apparatus.

4. Results and Discussion

4.1. Compressive strength

The compressive strength outcomes are outlined in Table 3 and Fig.6, with each value representing the average of each mixture. The substitution of fine aggregate with crumb rubber led to a gradual decrease in compressive strength. The use of 10% and 20% rubber (replacing the fine aggregate by volume) resulted in approximately 13% and 30% reductions in compressive strength at 7 and 28 days in comparison with the reference mixture (0R-0SF). Introducing 10% silica fume (0R-10SF) resulted in significantly enhancing the compressive strength by almost 61 %, recording 62.4 MPa, while 15% silica fume (0R-15SF) increased it to 53.4 MPa. The results indicated that 10% and 15% silica fume produced a comparable development in compressive strength to that reported in the mixture containing 10% rubber and no silica fume (10R-0SF). Consequently, the incorporation of 10% silica fume (10R-10SF) served to offset the reduction in compressive strength associated with the utilisation of 10% rubber. Nevertheless, with 20% rubber, the data revealed that 15% silica fume had a more substantial impact than 10%. Consequently, the inclusion of 15% silica fume (20R-15SF) partially mitigated the reduction in compressive strength resulted from the use of 20% rubber (20R-0SF). Thus, the proper amount of silica fume required increases with increasing the rubber content.

Table 3: Compressive strength from mixtures tested.

Mixes	Average compressive strength of three cubes (MPa)	
	7 days	28 days
0R-0SF	33.1	39.8
10R-0SF	28.9	34.6
20R-0SF	23.1	27.7
0R-10SF	45.4	62.4
10R-10SF	32.4	42.4
20R-10SF	26.1	32.8
0R-15SF	41.1	53.4
10R-15SF	33.3	42.0
20R-15SF	27.2	37.5

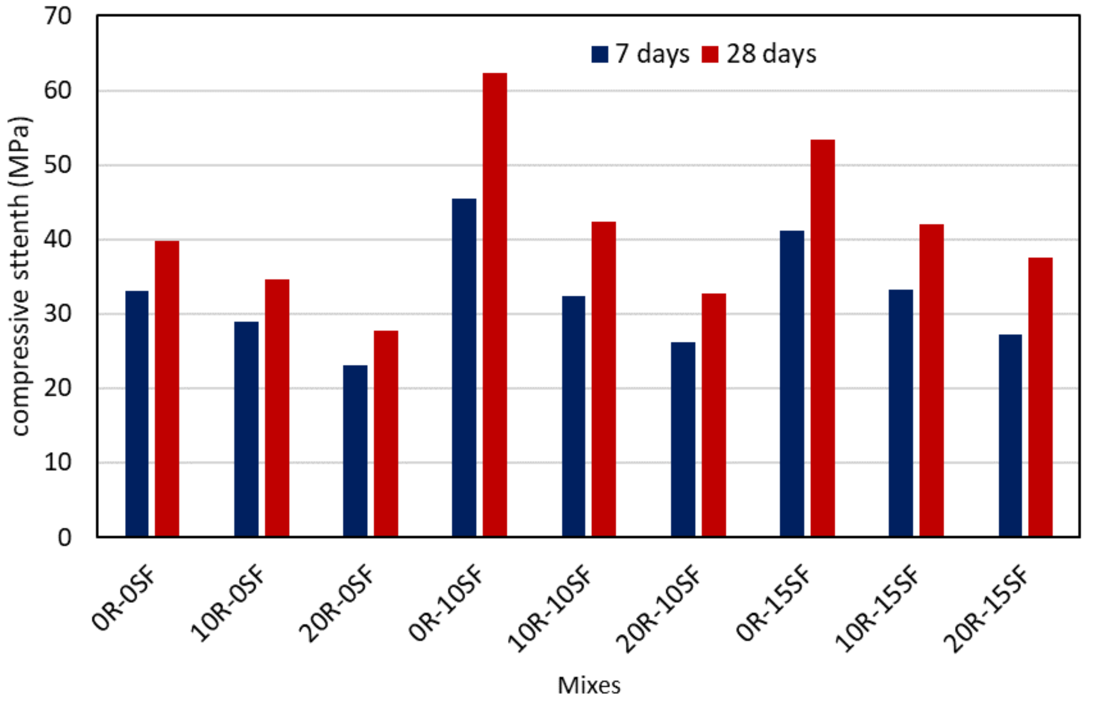


Fig. 6: The influence of different silica fume and rubber proportions on the compressive strength.

4.2. Density and water absorption

Fig.7 illustrates the experimental exploration of the impact of varying proportions of rubber and silica fume on the cured concrete's density and absorption. The graph indicates a decrease in density as the rubber content increases, albeit with a modest reduction, reaching a maximum density decrease of 5% compared to the control mixture (0R-0SF). In addition, the data indicates that incorporating silica fume results in a rise in density. Similarly, water absorption results reveal a slight increase as a result of the rubber tendency, but adding silica fume mitigates the water absorption by filling spaces between rubber particles, as depicted in Fig.8.

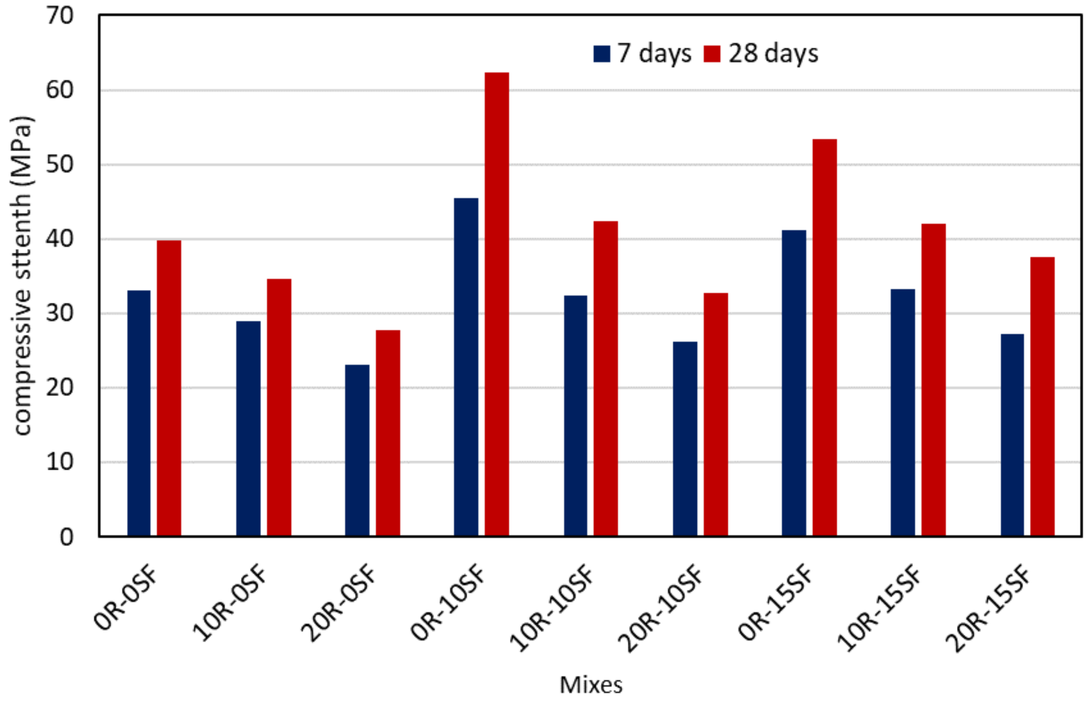


Fig. 7: Effect of varying silica fume and rubber proportions on concrete density.

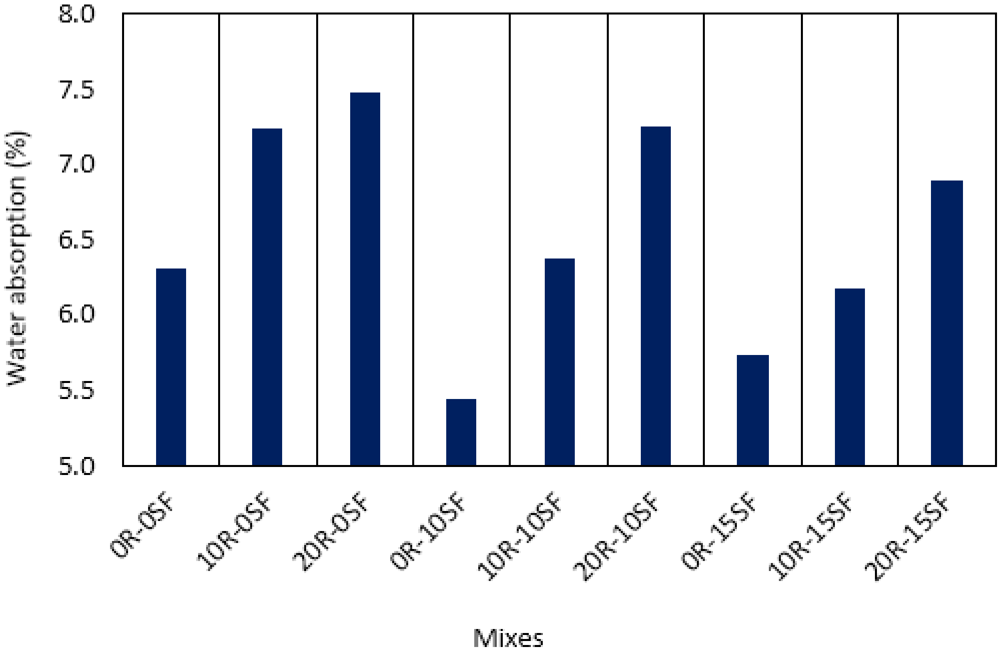


Fig. 8: Influence of varying silica fume and rubber proportions on concrete water absorption.

4.3. Thermal conductivity

This study investigated the thermal efficiency of rubberised concrete through thermal conductivity, as depicted in Fig.9 and Table 4. The outcomes revealed that augmenting rubber content resulted in a decline in thermal conductivity. Specifically, the introduction of 10% rubber led to a reduction in thermal conductivity to 1.67 W/mK, instead of 1.85 W/mK, reported in the control mixture, while with 20% rubber, it further decreased to 1.54 W/mK. This demonstrates that heightened rubber content diminishes heat transmission in rubberised concrete, enhancing its insulating properties compared to plain concrete. Moreover, a consistent drop in thermal conductivity was observed corresponding to the increased proportion of rubber in concrete mixtures. The study also highlighted a marginal adverse effect of silica fume on the thermal insulation of non-rubberised concrete mixtures. The incorporation of 10% silica fume in the non-rubberized mix (0R-10SF) increased thermal conductivity from 1.85 W/mK to 1.93 W/mK, whereas 15% silica fume in the non-rubberised mixture raised it to 1.98 W/mK. This might be ascribed to the filling action of silica fume. However, silica fume had a negligible impact on rubber replacement mixtures, resulting in equivalent insulating qualities. The findings indicated that the addition of 10% and 15% silica fume raised thermal conductivity from 1.67 W/mK to 1.7 W/mK and 1.72 W/mK, respectively, compared to the mix with 10% rubber and zero silica fume (10R-0SF). Moreover, the inclusion of 10% and 15% silica fume yielded thermal conductivities of 1.57 and 1.59 W/mK, respectively, while the mixture containing 20% rubber and no silica fume (20R-0SF) had a value of 1.54 W/mK. The data revealed that 20% rubber achieved the lowest thermal conductivity values, signifying the most significant improvement in thermal insulation qualities. Consequently, it can be inferred that rubberised concrete acts as a superior insulator with increased rubber utilization.

Table 4: Thermal conductivity of concrete mixtures.

Mixes	Thermal conductivity (W/mK)
0R-0SF	1.85
10R-0SF	1.67
20R-0SF	1.54
0R-10SF	1.93
10R-10SF	1.7
20R-10SF	1.57
0R-15SF	1.98
10R-15SF	1.72
20R-15SF	1.59

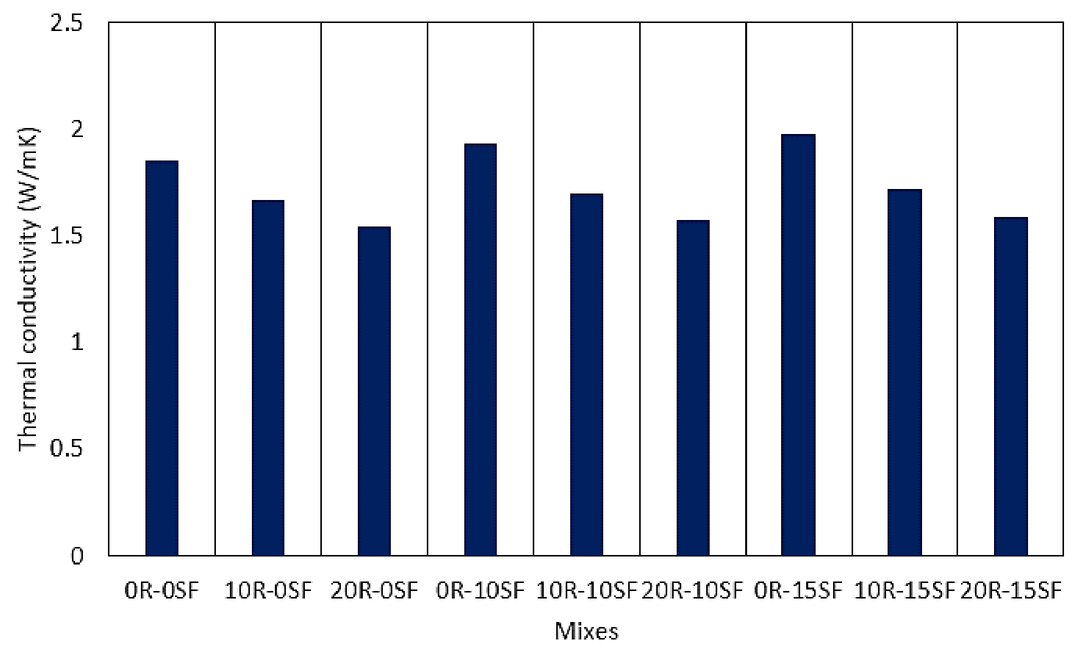


Fig. 9: Influence of varying silica fume and rubber proportions on concrete thermal conductivity.

5. Conclusion

The current investigation aimed at enhancing the mechanical and thermal characteristics of rubberised concrete through the inclusion of silica fume and determining the ideal proportion of crumb rubber and silica fume. The following conclusions may be drawn:

- As rubber content increased, a modest drop in density occurred, yet it was not significant, with a maximum 5% decrease compared to the reference mix. Silica fume slightly increased density due to its micro-filling action, reducing voids in the microstructure.
- Water absorption was influenced by rubber presence, but silica fume mitigated this effect by filling spaces between rubber particles.
- In terms of thermal characteristics, rubberized concrete demonstrated improved insulation with increasing rubber content, leading to reduced thermal conductivity.
- The mix (20%R-10%SF) performed well overall, achieving an acceptable compressive strength (32.8 MPa) (compared to the reference mix's 39.8 MPa) and a thermal conductivity value of 1.57 W/mK (compared to 1.85 W/mK for the reference mix), indicating enhanced thermal insulation.

References

[1] European tyre & rubber manufacturers' association (ETRMA), 2011. End of life tyres – A valuable resource with growing potential – 2010 edition. [Online] Brussels: ETRMA. Available at: http://www.etrma.org/pdf/20101220%20Brochure%20ELT_2010_final%20version.pdf

[2] Mangili, I., Lasagni, M., Anzano, M., Collina, E., Tatangelo, V., Franzetti, A., ... & Isayev, A. I. (2015). Mechanical and rheological properties of natural rubber compounds containing devulcanized ground tire rubber from several methods. *Polymer Degradation and Stability*, 121, 369-377.

[3] Archibong, F. N., Sanusi, O. M., Médéric, P., & Hocine, N. A. (2021). An overview on the recycling of waste ground tyre rubbers in thermoplastic matrices: Effect of added fillers. *Resources, Conservation and Recycling*, 175, 105894.

[4] Eiras, J. N., Segovia, F., Borrachero, M. V., Monzó, J., Bonilla, M., & Payá, J. (2014). Physical and mechanical properties of foamed Portland cement composite containing crumb rubber from worn tires. *Materials & Design*, 59, 550-557.

[5] Azevedo, F., Pacheco-Torgal, F., Jesus, C., De Aguiar, J. B., & Camões, A. F. (2012). Properties and durability of HPC with tyre rubber wastes. *Construction and building materials*, 34, 186-191.

[6] Akbar, M., Hussain, Z., Huali, P., Imran, M., & Thomas, B. S. (2023). Impact of waste crumb rubber on concrete performance incorporating silica fume and fly ash to make a sustainable low carbon concrete. *Struct. Eng. Mech*, 85, 275-287.

[7] Shu, X., & Huang, B. (2014). Recycling of waste tire rubber in asphalt and portland cement concrete: An overview. *Construction and Building Materials*, 67, 217-224.

[8] World business council for sustainable development (WBCSD), 2008. Managing end-of-life tires (full report). [Online] Switzerland: Atar roto presse SA. Available at: http://www.wbcsd.org/includes/getTarget.asp?type=d&id=MzI0NDA

[9] Karger-Kocsis, J., Mészáros, L., & Bárány, T. (2013). Ground tyre rubber (GTR) in thermoplastics, thermosets, and rubbers. *Journal of Materials Science*, 48, 1-38.

[10] Danielli Bastos de Sousa, F., Scuracchio, C. H., Hu, G. H., & Hoppe, S. (2016). Effects of processing parameters on the properties of microwave-devulcanized ground tire rubber/polyethylene dynamically revulcanized blends. *Journal of Applied Polymer Science*, 133(23).

[11] Eldin, N. N., & Senouci, A. B. (1993). Rubber-tire particles as concrete aggregate. *Journal of materials in civil engineering*, 5(4), 478-496.

[12] Ramarad, S., Khalid, M., Ratnam, C. T., Chuah, A. L., & Rashmi, W. (2015). Waste tire rubber in polymer blends: A review on the evolution, properties and future. Progress in Materials Science, 72, 100-140.

[13] Senin, M. S., Shahidan, S., Abdullah, S. R., Guntor, N. A., & Leman, A. S. (2017, November). A review on the suitability of rubberized concrete for concrete bridge decks. *In IOP Conference Series: Materials Science and Engineering* (Vol. 271, No. 1, p. 012074). IOP Publishing.

[14] Thomas, B. S., & Gupta, R. C. (2016). A comprehensive review on the applications of waste tire rubber in cement concrete. *Renewable and Sustainable Energy Reviews*, 54, 1323-1333.

[15] Sofi, A. (2018). Effect of waste tyre rubber on mechanical and durability properties of concrete–A review. *Ain Shams Engineering Journal*, 9(4), 2691-2700.

[16] Mohammadi, I. (2014). Investigation on the use of crumb rubber concrete (CRC) for rigid pavements (Doctoral dissertation).

[17] Kardos, A. J. (2011). Beneficial use of crumb rubber in concrete mixtures. University of Colorado at Denver.

[18] Holmes, N., Browne, A., & Montague, C. (2014). Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement. *Construction and Building Materials*, 73, 195-204.

[19] Khatib, Z. K., & Bayomy, F. M. (1999). Rubberized Portland cement concrete. *Journal of materials in civil engineering*, 11(3), 206-213.

[20] Youssf, O., ElGawady, M. A., Mills, J. E., & Ma, X. (2014). An experimental investigation of crumb rubber concrete confined by fibre reinforced polymer tubes. Construction and Building Materials, 53, 522-532.

[21] Aniruddh, M., Kumar, A., & Khan, M. A. (2016). Effect on compressive strength of concrete by using waste rubber as partial replacement of fine aggregate: A review. *Int. Res. J. Eng. Technol*, 3, 86-89.

[22] Ling, T. C. (2011). Prediction of density and compressive strength for rubberized concrete blocks. *Construction and Building Materials*, 25(11), 4303-4306.

[23] Youssf, O., & Elgawady, M. A. (2012). An overview of sustainable concrete made with scrap rubber.

[24] Siddique, R. (2011). Utilization of silica fume in concrete: Review of hardened properties. Resources, *Conservation and Recycling*, 55(11), 923-932.

[25] Panjehpour, M., Ali, A. A. A., & Demirboga, R. (2011). A review for characterization of silica fume and its effects on concrete properties. *International Journal of Sustainable Construction Engineering and Technology*, 2(2).

[26] Gesoğlu, M., Güneyisi, E., Khoshnaw, G., & İpek, S. (2014). Investigating properties of pervious concretes containing waste tire rubbers. *Construction and Building Materials*, 63, 206-213.

[27] ASTM, A. (2017). C33/C33M, Standard Specification for Concrete Aggregates.

[28] Standard, B. (2009). Testing hardened concrete. Compressive Strength of Test Specimens, BS EN, 12390-3.

[29] Marie, I. (2017). Thermal conductivity of hybrid recycled aggregate–Rubberized concrete. *Construction and Building Materials*, 133, 516-524.

[30] Misri, Z., Ibrahim, M. H. W., Awal, A. S. M. A., Desa, M. S. M., & Ghadzali, N. S. (2018, April). Review on factors influencing thermal conductivity of concrete incorporating various type of waste materials. *In IOP conference series: earth and environmental science* (Vol. 140, No. 1, p. 012141). IOP Publishing.