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THERMOPHYSICAL PROPERTIES OF CONCRETE BLENDED WITH IRON POWDER AND/OR IRON FIBERS

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Abstract

The use of iron waste in concrete is now of considerable importance, mainly because of the benefits for the environment and for improving the strength of concrete. The increased and unused of this industrial by-products represents a challenge for the environment and human health. This article experimentally explores the influence of utilizing iron powder waste and iron fibers in concrete in order to enhance the thermophysical properties of concrete and reduce the environmental impact resulting from iron waste. The aim of this work is to study the thermophysical properties (thermal conductivity, volumetric heat capacity, thermal diffusivity and thermal effusivity) of concrete with waste iron powder and iron fibers for application in building construction. The iron powder waste was added to the concrete with different percentages of 0%, 5%, 15%, 20% and 25% respectively as a partial replacement of sand. The iron fibers were added with mix proportions including 1.0%, 1.5%, 2.0% and 2.5% by volume of concrete, and in two different arrangements, uniform and random. The thermal conductivity and the volumetric heat capacity of these samples were measured experimentally in the dry state at ambient temperature (20 °C), and at 28 days of age. The effect of the integration of iron powder and fiber on thermal properties was analysed.

Keywords:

Concrete;
Iron Powder Waste;
Iron fiber;
Thermal conductivity;
Volumetric Heat capacity.

1 Introduction

The building and construction sector is generally characterized by both increasing emissions and energy consumption, combined with a further slowdown in investment in energy efficiency. Concrete possesses several advantageous properties such as fire resistance, high compressive strength, and ease of shaping into desired forms [1]. Furthermore, it is the most commonly used building material due to its durability, flexibility, and low production and maintenance costs [2]. The evaluation of thermophysical properties, encompassing thermal conductivity, specific heat, thermal effusivity, and thermal diffusivity, holds significant importance in various disciplines, such as energy engineering, chemical engineering, materials engineering, and civil engineering. In the case of concrete, thermal diffusivity, thermal conductivity, and specific heat capacity constitute the principal factors that dictate the thermal response of civil and environmental projects. The thermal conductivity of cementitious materials, such as concrete, is an important parameter to measure the ability of concrete to conduct heat and depends on moisture content, temperature, type of aggregate, type of cement, density and porosity [3]–[5].

Sand, primarily utilized as a fine aggregate in concrete production, is typically extracted from riverbeds through dredging. However, this practice presents a significant sustainability challenge in the 21st century due to its adverse impact on the environment. The availability of natural aggregates is gradually decreasing and their cost is also rising. Moreover, it is imperative to take into account the annual quantity of aggregate utilized in global concrete production, which was estimated to exceed 10-11 billion tons 20 years ago [6], [7].

Iron powder waste is a residual material generated as a by-product of industrial processes such as cutting, grinding, and polishing of finished iron products, which are commonly carried out in

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workshops and foundries [8], [9]. This product negatively impacts the environment during its disposal, hence the increasing amount of iron powder waste is one of the major environmental problems in the world. Therefore, the use of industrial waste such as iron filings in concrete production would improve the quality of environmental waste [7]. Sand is used as a major constituent for the production of concrete and building materials [10] , The depletion of natural reserves of sand used in the construction industry and the disposal of waste are important risk factors [7], [8]. Hence, the reutilization of iron powder waste serves dual objectives. The first objective entails mitigating the pollution that arises from the accumulation of this waste, while the second objective involves the provision of resources for concrete aggregates. This, in turn, facilitates an enhancement of the thermophysical properties of the concrete. Studies have shown that IPW can potentially and durability be used as a partial substitution for NS in concrete production [11]–[15]. However, few studies are focused on the thermal proprieties of iron powder in concrete. Adeyanju and Manohar [16] studied the thermal properties of iron filings and steel fibers in concrete for solar/thermal energy storage application. The experimental method is based on concrete mixtures with three different sizes of aggregates and the same amount of steel fibers, two different amounts of iron filings, and ordinary concrete. The purpose of this work was to study the thermal performance, thermal conductivity, thermal resistivity and thermal diffusivity. The results indicate that the presence of steel fibers and iron filings have an influence on the thermal and mechanical properties of the tested concretes, it also increases the thermal conductivity and thermal storage capacity of the concrete. It is imperative to acknowledge that fiber-reinforced concrete, which incorporates the integration of metal fibers, is extensively employed as a structural material for a wide range of applications such as industrial floors, roadways, and airport runways [17]. Although the incorporation of fibers into ordinary concrete improves the properties of the concrete to a certain level, the inclusion of fibers in the concrete mixture produces a significant improvement in its properties [18]. However, steel fibers are the most widely used in concrete. This is because the performance of steel fibers increases the mechanical properties of concrete, such as compression strength [19]–[21]. In the literature, there are researches on the incorporation of iron fibers in concrete [22]–[24].

Most of the studies mentioned previously have investigated the effects of the incorporation of iron powder and/or fibers in concrete on mechanical properties such as compressive strength, flexural strength, durability and splitting tensile strength of concrete. Moreover, the thermophysical properties of concrete incorporating fibers and iron powder are limited in some research. The objective of this research is to conduct experimental investigations pertaining to the thermophysical parameters, including thermal conductivity, specific heat, thermal diffusivity, and thermal effusivity, of various types of concrete. This study aims to explore the impact of iron powder content, ranging from 0% to 25%, applied compaction, and the addition of iron fibers, ranging from 0% to 2.5%, on these parameters at 28 days of age and at ambient temperature.

2 Materials

The experimental program employed a range of materials, including Ordinary Portland Cement CPJ 45, coarse aggregate, fine aggregate(sand),iron fiber, iron powder waste, and water.

2.1 Cement

The cement used in this study is Portland cement CPJ 45, which is produced through crushing clinker at a proportion of 65% or greater, in combination with one or more secondary constituents such as fillers, pozzolans, or fly ash as per NM 10.1.004 regulations.

2.2 Coarse aggregates

The coarse aggregates readily available in the local area were chosen for experimentation, as shown in Fig. 1. These aggregates had particle size distributions ranging from 8 to 25 mm. The coarse aggregates have been washed and dried in the oven at 80 ºC for 24 hours.



Fig. 1: Coarse aggregates.

2.3 Sand

The sand used in this research was obtained from a nearby river in the Rabat Sale region. After extraction, the sand underwent a washing process and was dried for 24 hours at 80 ºC. The particle size distribution of the sand is illustrated in Fig. 3.

2.4 Iron powder waste and Iron fibers

Iron Powder, as shown in Fig. 2a, is a by-product obtained from a metallurgy workshop in the Rabat-Sale region. The iron powder waste consists mainly of iron oxide fines with traces of other chemicals. The particle size analysis of the iron powder is shown in Fig. 3.

In the present study, the iron fibers used are 50 mm in length and circular section with a diameter of 1.33 mm were added to the concrete at low volume doses Fig. 2b.



(a) (b)

Fig. 2: (a) Iron Fibers; (b) Iron Powder Waste.

The particle size analysis presents the percentage distribution of sand and iron powder particles according to their dimensions. Fig. 3 shows the particle size distribution of sand and iron powder waste. It was determined by sieving the grains whose diameter is between 0.08 mm and 0.8 mm. The sieves are ordered from bottom to top, from smallest to largest diameter. The sieving test procedure was performed using 500 g of sand and iron powder waste. These results are from an electronic sieve shaker model Glenammer GEM 200D.

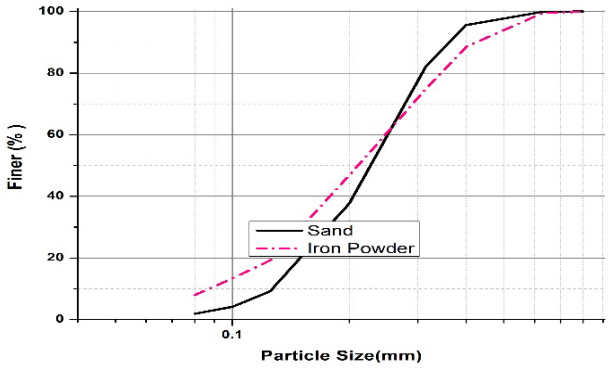


Fig. 3: Particle size distribution of Sand and Iron Powder.

3 Experimental setup

3.1 Concrete samples preparation

The concrete used for this study was M20 grade concrete with a nominal mix ratio of 1:1.5:3 for cement, fine aggregate and coarse aggregate. For each mix design, the W/C was kept at 0.52. The composition of concrete samples is shown in Table 1.

To perform the thermophysical properties tests, two types of concrete mixtures in a rectangular mold (dimensions 75x50x90 mm^3) have been prepared:

Waste iron powder was incorporated into concrete mixtures, MIP (Iron Powder waste in Concrete). The study involved the creation of six pairs, with each set containing varying amounts of iron powder replacing the sand. The replacement levels ranged from 0% to 25% in 5% increments (Fig. 4).

The Iron Fiber Reinforced Concrete (IFRC) is based on the preparation of four pairs of samples with iron fiber contents of 1%, 1.5%, 2% and 2.5% by volume of concrete for each type of fiber distribution. Fibers were added to fresh concrete in two different distributions: a) uniform fiber arrangement, b) random fiber arrangement, as depicted in Fig. 5.

Table 1: Mixing composition of concrete.

Proportion	Cement (kg/m^3)	Sand (kg/m^3)	CoarseAggr. (kg/m^3)	Water (kg/m^3)	IP/IF (kg/m^3)
NC	410	615	1230	205	0
MIP5	410	584.2	1230	205	30.72
MIP10	410	553.5	1230	205	61,5
MIP15	410	522,75	1230	205	92.25
MIP20	410	492	1230	205	123
MIP25	410	461.25	1230	205	153.75
MIF(1%)	410	615	1230	205	24.6
MIF(1.5%)	410	615	1230	205	36.9
MIF(2%)	410	615	1230	205	49.2
MIF(2.5%)	410	615	1230	205	61.5

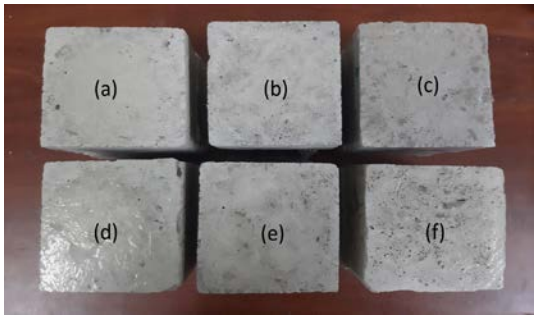


Fig. 4: (a) MIP0+ 0% IP; (b) MIP5+ 5% IP; (c) MIP10+ 10% IP; (d) MIP15+ 15% IP; (e) MIP20+ 20% IP; (f) MIP25+ 25% IP.



Fig. 5: (A1) NCG2 U + 1% IF; (A2) NCG2 U + 1.5% IF; (A3) NCG2 U + 2% IF; (A4) NCG2 U + 2.5% IF; (B1) NCG2 R + 1% IF; (B2) NCG2 R + 1.5% IF; (B3) NCG2 R + 2% IF; (B4) NCG2 R + 2.5% IF.

3.2 Instrumentation and measurements

The thermal conductivity λ ($W \cdot m^{-1} \cdot K^{-1}$) and the volumetric heat capacity Cp ($KJ/m^3 \cdot K$) of the various specimens were evaluated using a CT-meter manufactured by Modern Electronic Studies (VOIRON, France) at ambient temperature (20°C). The CT-meter measures the thermal conductivity and volumetric heat capacity by monitoring the temperature rise over a 500-second measurement period using a flexible probe Ring-shaped with a thickness of 0.2 mm, with dimensions of 60 mm × 90 mm and a radius of 10 mm. The probe, which is inserted between two identical samples, comprises a resistive wire and a thermocouple, both of which are housed in an insulating Kapton support. The reported values represent the mean of three measurements. The standard measurement uncertainty was 5% [25], [26], the experimental setup is shown in Fig. 6. The CT Meter enables the experimental determination of the thermal conductivity and volumetric heat capacity in accordance with NF EN 993-15 of 2005,[27], [28],[29].



Fig. 6: CT meter**.**

4 Test results of iron powder (IPW) concrete mixes

4.1 Concrete samples preparation

The bulk density ρ ($kg \cdot m^{-3}$) of each type of samples was calculated using the dimensions and weight of the dry samples.

$$\rho = \frac{m}{V} \quad (1)$$

where:
m (kg) – definition of the mass of the dried sample,
V (m^3) – the sample volume.

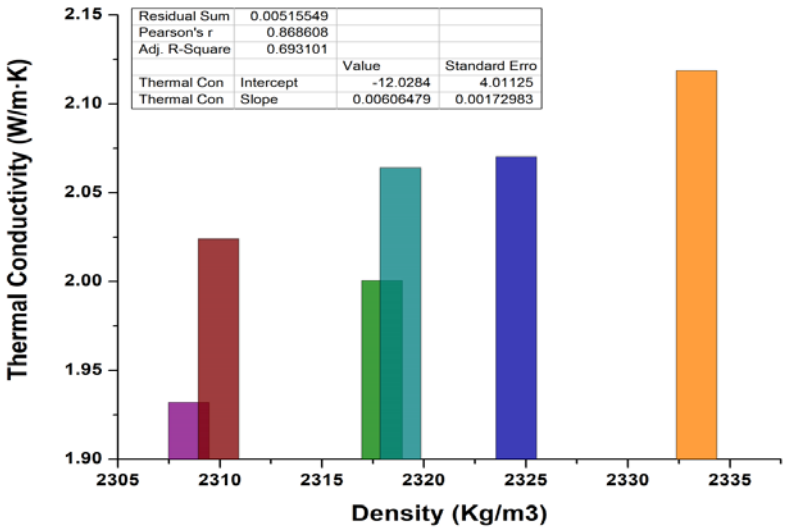


Fig. 7: The relationship between bulk density and thermal conductivity.

Thermal conductivity and bulk density (equation (1)) were determined for the reference sample and for samples with different percentages of iron powder waste. The reference sample (NC) has an average thermal conductivity of was 1.93 W/m·K with a density of 2308 kg/m^3. The samples with iron powder waste showed higher thermal conductivity and density than the control sample. The thermal conductivities of samples with 5%, 10%, 15%, 20% and 25% of iron powder waste (IPW) were 2.02 W/m·K, 2.0 W/m·K, 2.06 W/m·K, 2.07 W/m·K and 2.12 W/m·K respectively. The average density of samples with iron powder waste percentages of 5%, 10%, 15%, 20% and 25% were 2309 kg/m^3, 2317 kg/m^3, 2318 kg/m^3, 2324 kg/m^3 and 2333 kg/m^3 respectively. The thermal conductivity and the bulk density of the samples with varying percentages of iron powder are presented in Fig. 7. The variation in thermal conductivity is a linear function of bulk density for different iron powder contents. The thermal conductivity of samples increases with increasing bulk density. Bellil et al. [30] and Collet and Pretot [26] show that the thermal conductivity of concrete increases linearly with increasing density[31]. The apparent density of the sample increases, porosity decreases and thermal conductivity increases. The dependence of the thermal conductivity on the apparent density of the concrete can be explained by the low porosity of the samples, so it can be said that increasing the iron powder waste (WIP) content reduces the pore volume, increasing the density and hence the thermal conductivity of the concrete.

4.2 Relationship between the percentage of Iron Powder and Thermal Conductivity

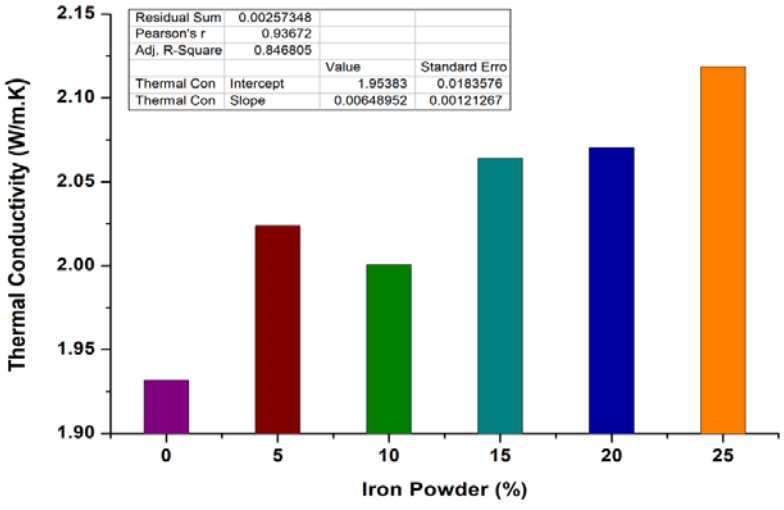


Fig. 8: The influence of iron powder on thermal conductivity.

The thermal conductivity of the samples was determined a CT-meter. The thermal conductivities of MIP5 (5% IP), MIP10 (10% IP), MIP15 (15% IP), MIP20 (20% IP) and MIP25 (25% IP) mixtures were 2.02 W/m·K, 2.0 W/m·K, 2.06 W/m·K, 2.07 W/m·K, 2.12 W/m·K respectively. Tests showed that the thermal conductivity of concrete specimens with IP continued to increase with increasing iron powder content. At an iron powder content of 25%, the increase in thermal conductivity was the maximum increase and was around 8.6%. Thermal conductivity values for samples made with different percentages of iron powder are shown graphically in Fig. 8. It can be noticed that there is a positive trend in the thermal conductivity with an increase in the quantity of iron powder incorporated into the concrete mixture. In addition, the concrete with a replacement percentage of 25% by the iron powder waste (WIP) showed the highest value of thermal conductivity, which increased (from 1.93 W/m·K to 2.12 W/m·K) with a percentage of 8.6% higher than the normal concrete. This elevation of thermal conductivity can be explained by the conduction of high heat of the iron and also by the increase in density of concrete samples with the percentages of iron powder added. These results are in agreement with those of [16], who showed that the thermal conductivity of the concrete increase slightly with the addition of iron filings. This result is similar to that obtained by [32], in which the thermal conductivity of the geopolymer composite increased with the addition of Fe.

4.3 Relationship between the percentage of Iron Powder and Volumetric Heat Capacity

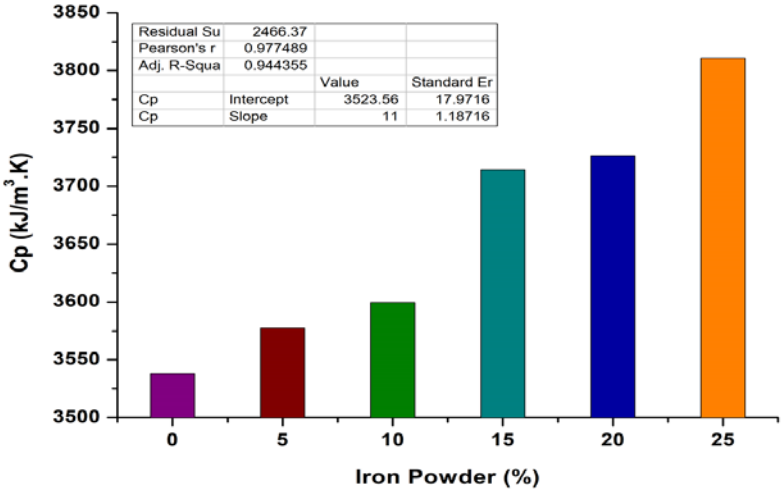


Fig. 9: The influence of iron Powder on volumetric heat capacity.

The specific heat capacities of samples with different percentages of iron powder are shown in Fig. 9. The samples with iron powder displayed a higher specific heat capacity than the control sample. The specific heat capacity of the control sample (NC) at 28 days of curing was 3538 KJ/m^3·K. The specific heat capacity of the concrete tested for the different percentages of iron powder MIP5 (5% IP), MIP10 (10% IP), MIP15 (15% IP), MIP20 (20% IP) and MIP25 (25% IP) were 3577 KJ/m^3·K, 3599 KJ/m^3·K, 3714 KJ/m^3·K, 3726 KJ/m^3·K, 3810 KJ/m^3·K respectively. As shown in Fig. 9, the volumetric heat capacity increases linearly with the incorporation of iron powder. This increase is estimated by a maximum value going from 3538 kJ/m^3·K for the reference sample to 3810 kJ/m^3·K for a percentage of 25% with a rate of 7.14%. The volumetric heat capacity depends mainly on the density and volumetric heat capacity of the different components of concrete. It can be noted that this increase in thermal capacity is proportional to thermal conductivity.

4.4 Relationship between the percentage of Iron Powder and Thermal Diffusivity

The determination of the thermal diffusivity of concrete samples is achieved by applying the following relationship (2):

$$\mathrm{D} = \frac{\lambda}{Cp} \quad (2)$$

where:
λ (w/m·K) – definition of the thermal conductivity,
Cp (KJ/m^3·K) – the volumetric specific heat.

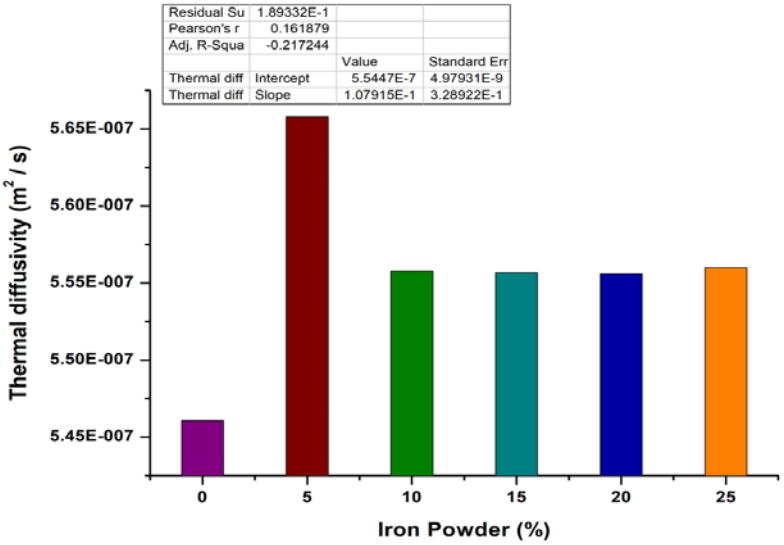


Fig. 10: The influence of iron powder on thermal diffusivity.

The thermal diffusivity of the samples was determined for the control sample as well as samples with different percentages of iron powder. The thermal diffusivity of the control sample at 28 days (NC) was 5.46x 10^{-7} m^2/s. The thermal diffusivity of concrete tested for MIP5 (5% IP), MIP10 (10% IP), MIP15 (15% IP), MIP20 (20% IP) and MIP25 (25% IP) mixes were 5.46x 10^{-7} m^2/s, 5.66x 10^{-7} m^2/s, 5.56x 10^{-7} m^2/s, 5.56x 10^{-7} m^2/s, 5.56x 10-7 m2/s, 5.56x 10^{-7} m^2/s respectively. Thermal diffusivity values for samples made with different percentages of iron powder are shown graphically in Fig. 10. Samples with iron powder showed higher thermal diffusivity for the MIP5 (5% IP). The thermal diffusivity of the other samples increased slightly by 1.8% on average with the addition of 10%, 15%, 20% and 25% waste iron powder, respectively. Tests showed that the optimum percentage of iron powder to achieve the maximum increase in thermal diffusivity was 5%. For a partial replacement of 25% of the sand by iron powder, the increase in thermal diffusivity was relatively low. Thermal diffusivity is a physical quantity that depends on the thermal conductivity of concrete and its ability to store heat (volumetric heat capacity). These results are in agreement with those of [33], who showed that the reduction in thermal conductivity conducts a decrease in thermal diffusivity. Indeed, thermal diffusivity and conductivity are proportional.

4.5 Relationship between the percentage of Iron Powder and Thermal Effusivity

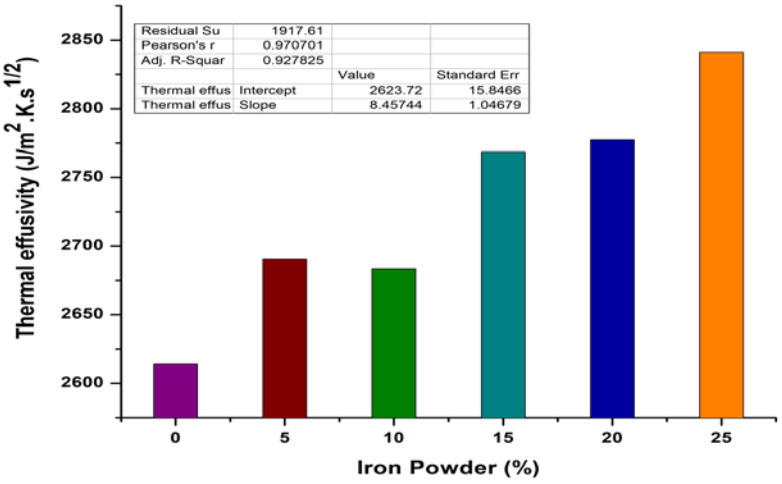


Fig. 11: The influence of iron powder on thermal Effusivity.

The thermal Effusivity (E) was estimated by the following equation:

$$E = \sqrt{\lambda Cp} \quad (3)$$

where:
λ (w/m·K) – definition of the thermal conductivity,
Cp (KJ/m^3·K) – the volumetric specific heat.

The thermal effusivity of the control sample at 28 days (NC) was 2614 J/m^2·K·s$^{1/2}$. Samples with iron powder showed higher thermal effusivity than the control sample. The thermal effusivity of mix designs MIP5 (5% IP), MIP10 (10% IP), MIP15 (15% IP), MIP20 (20% IP) and MIP25 (25% IP) were 2690 J/m^2·K·s$^{1/2}$, 2683 J/m^2·K·s$^{1/2}$, 2768 J/m^2·K·s$^{1/2}$, 2777 J/m^2·K·s$^{1/2}$ and 2841 J/m^2·K·s$^{1/2}$ respectively. Thermal effusivity values with different percentages of iron powder are shown graphically in Fig. 11. The results indicate that the thermal effusivity of concrete increases linearly with the partial replacement of fine aggregate (sand) by iron powder waste .Thermal effusivity undergoes an increase of 7.987% when 25% iron powder waste is incorporated, which means an escalation in the rate of heat absorption and emission (heat exchange) between this category of concrete and its environment. The augmentation in this thermophysical parameter is primarily attributed to the rise in thermal conductivity and specific heat of the corresponding specimens.

5 Test results of iron Fibers (IF) concrete mixes

5.1 Effect of Iron Fiber content and Fiber arrangement on Thermal Conductivity and Volumetric Heat Capacity

The thermal conductivity of concrete made with iron fibers (IF) was measured using CT meter for two different fiber arrangements, as shown in Fig. 12. The thermal conductivity of the samples was determined for the control sample as well as the samples with various percentages of iron fibers. The thermal conductivity of the control sample at 28 days was 1.93 W/(m·K). Samples with iron fibers showed higher thermal conductivity than the control sample for the uniform fiber arrangement case. The thermal conductivities of mix designs with uniform fibers arrangement MIF1 (1% IF), MIF2 (1.5% IF), MIF3 (2% IF) and MIF4 (2.5% IF) were 2.03 W/(m·K), 2.10 W/(m·K), 2.11 W/(m·K) and 2.16 W/(m·K) respectively. The thermal conductivities of mix designs with a random fibers arrangement of MIF5 (1% IF), MIF6 (1.5% IF), MIF7 (2% IF) and MIF8 (2.5% IF) fibers were 1.93 W/(m·K), 1.93 W/(m·K), 1.85 W/(m·K) and 1.99 W/(m·K) respectively. The thermal conductivity increases up to 2.159 W/(m·K) upon the attainment of 2.5% iron fibers by volume in the concrete, with a growth rate of 10.51% for the uniform arrangement of iron fibers. In the case of a random distribution of fibers, the thermal conductivity experiences a slight increment up to 1.994 W/(m·K) at a fiber percentage of 2.5% of the total concrete volume, the rate of increase equals 3.11%. It is further observed that for random arrangement of fibers, there is a decline in thermal conductivity, estimated to be approximately 4.29% at a fiber percentage of 2%.

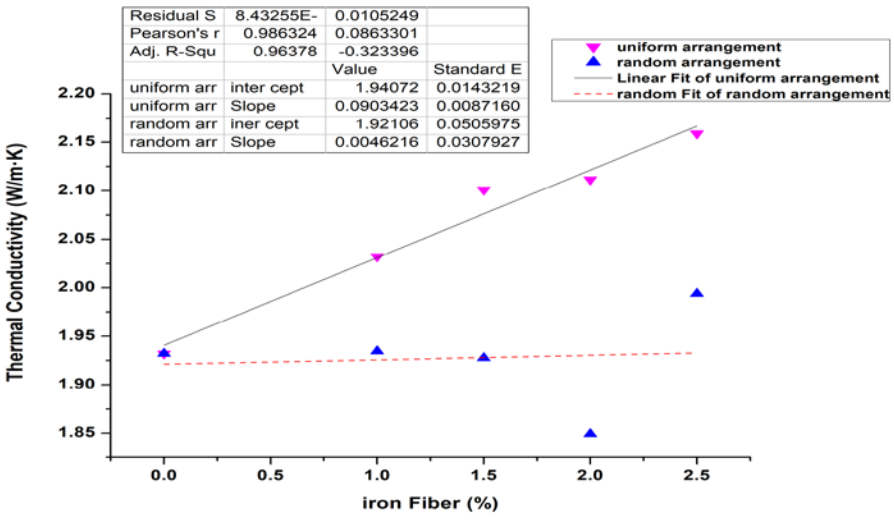


Fig. 12: The influence of Iron Fibers on Thermal Conductivity.

As anticipated, the results indicate a linear augmentation in thermal conductivity with the increment in the proportion of iron fibers for the uniform arrangement. This phenomenon can be attributed to the high thermal conductivity of iron, coupled with the even distribution of fibers within the concrete. Increasing the volume of fibers does not necessarily increase the thermal conductivity of concrete because the random arrangement of fibers can introduce air into the sample and increase the porosity, resulting in a lower thermal conductivity [19].

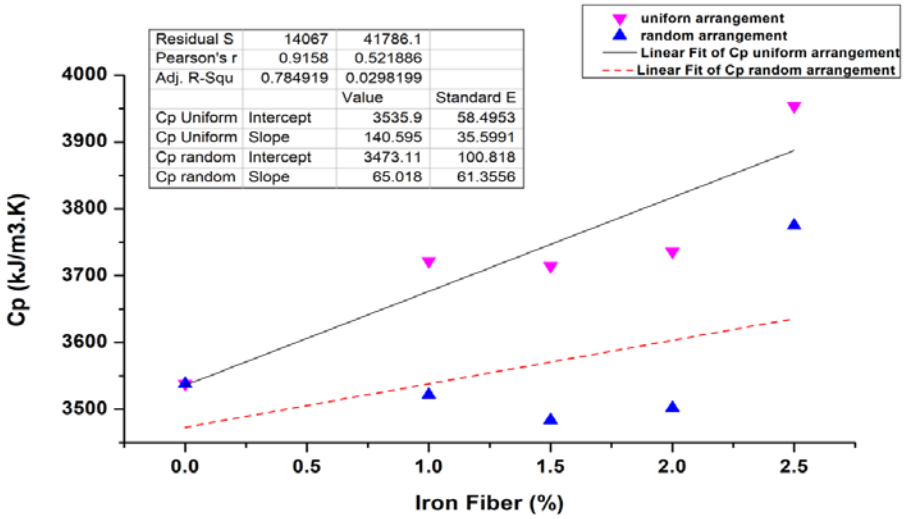


Fig. 13: The influence of Iron Fibers on volumetric heat capacity.

The volumetric heat capacity of the samples were determined for the control sample and for samples with mix proportions including 0%, 1.0%, 1.5%, 2.0% and 2.5% by volume of concrete for each iron fibers distribution. The volumetric heat capacity of the control sample (NC) at 28 days was 3538 kJ/m^3·K. The samples with uniform iron fibers arrangement showed a higher volumetric heat capacity. The volumetric heat capacities of MIF1 (1% IF), MIF2 (1.5% IF), MIF3 (2% IF) and MIF4 (2.5% IF) mixtures were 3721 kJ/m^3·K, 3714 kJ/m^3·K, 3736 kJ/m^3·K and 3953 kJ/m^3·K respectively. The volumetric heat capacities of MIF5 (1% IF), MIF6 (1.5% IF), MIF7 (2% IF) and MIF8 (2.5% IF) mixtures were 3521 kJ/m^3·K, 3483 kJ/m^3·K, 3502 kJ/m^3·K and 3775 kJ/m^3·K respectively. The values of volumetric heat capacities of samples made with different percentages of iron fibers for each distribution are presented in Fig. 13.

Analysis of the experimental graph showed that the volumetric heat capacity increased linearly with the inclusion of iron fibers for uniform distribution. The maximum rate of increase is estimated by a value of 11.73% for a percentage of 2.5%. The figure presented here shows that the volumetric heat capacity values, obtained by experimentation for the random distribution of fibers, show a singular significant increase of 3775 kJ/m^3. This increase is associated with a rate of 6.69%, resulting from the incorporation of 2.5% iron fiber. From the results, it can be noted that this decrease in thermal capacity is proportional to thermal conductivity and porosity.

5.2 Effect of Iron Fiber content and Fiber arrangement on Thermal Diffusivity and Effusivity of Concrete

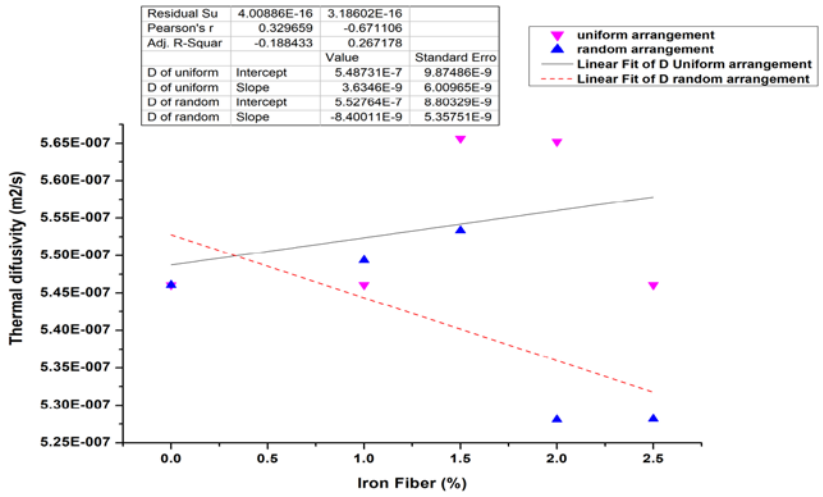


Fig. 14: The influence of Iron Fibers o thermal diffusivity.

The thermal diffusivity of the samples was determined for the control sample and for the samples with different percentages of iron fibers for two different fiber arrangements. The thermal diffusivity of the control sample at 28 days (NC) was 5.46x 10^{-7} m^2/s. The thermal diffusivity of the other samples with a uniform arrangement of iron fibers MIF1 (1% IF), MIF2 (1.5% IF), MIF3 (2% IF) and MIF4 (2.5% IF) were 5.46x 10^{-7} m^2/s, 5.66x 10^{-7} m^2/s, 5.65x 10^{-7} m^2/s and 5.46x 10^{-7} m^2/s respectively. The thermal diffusivities of MIF5 (1% IF), MIF6 (1.5% IF), MIF7 (2% IF) and MIF8 (2.5% IF) mixtures were 5.49x 10^{-7} m^2/s, 5.53x 10^{-7} m^2/s, 5.28x 10^{-7} m^2/s, 5.28x 10^{-7} m^2/s respectively. Thermal diffusivity values for samples made with different percentages of iron fibers are shown graphically in Fig. 14.

The thermal diffusivity of the concrete samples with uniform fiber arrangement increased slightly by an average of 3.53%, 3.36% with the addition of 1.5% and 2% of fibers, respectively. For a percentage of 2.5% the thermal diffusivity value is almost the same compared to 0%. The thermal diffusivity values corresponding to the random distribution of fibers show an increase of approximately 1.26% and 3.36% with the inclusion of 1% and 1.5% fibers, respectively. In contrast, a decrease of 3.3% is observed when incorporating of 2% and 2.5% iron fibers. The decrease in this thermophysical parameter depended mainly on the significant increase in specific heat capacity versus thermal conductivity of these concrete samples. Which implies that the decrease in thermal diffusivity observed is mainly due to the variation in thermal conductivity of samples [34].

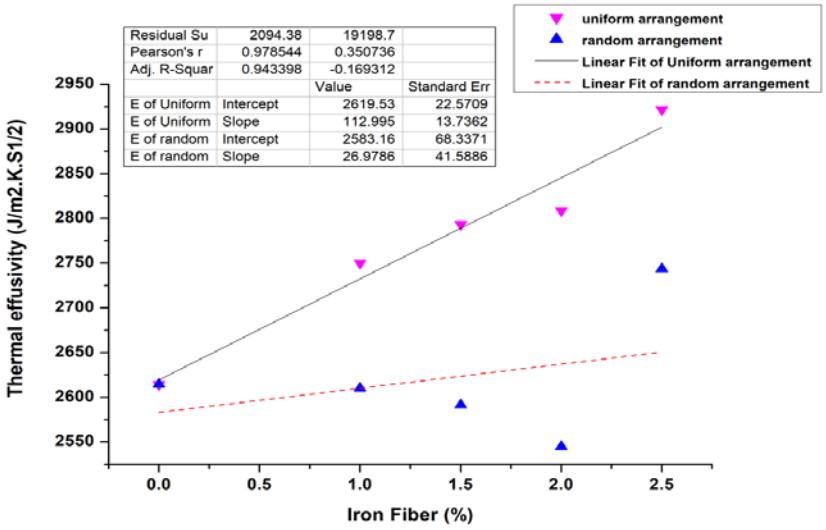


Fig. 15: The influence of Iron Fibers o thermal Effusivity.

The thermal effusivity values, as shown in Fig. 15 were calculated using equation (3). The thermal effusivity of the same fiber concrete samples increased linearly for the uniform arrangement of iron fibers on average by 4.94%, 6.41%, 6.92%, and 10.51% with the addition of 1%, 1.5%, 2%, and 2.5% iron fibers, respectively. For the random arrangement of fibers, we notice an increase in thermal effusivity with the addition of 2.5% iron fibers estimated at a rate of 4.71%. Therefore, the thermal effusivity depends on the thermal conductivity and then on the volumetric heat capacity.

Conclusion

In the laboratory setting, experimental investigations were carried out to determine the thermophysical properties of concrete in the presence of iron powder and iron fibers. Additionally, the influence of compaction and the size of coarse aggregate on thermal characteristics was also evaluated.

Based on the outcomes of the study, the following primary conclusions can be made:

• The results revealed that concrete incorporating G2 size aggregates has superior thermal characteristics compared to G1 size aggregates. Notably, compaction at a level of 1000g for NCG2 produces a 3% increase in thermal conductivity, an 8.49% increase in volumetric heat capacity, an 8.76% increase in bulk density, and a 6.08% increase in thermal effusivity. In contrast, thermal diffusivity is found to decrease at a rate of 5.067%.

• The incorporation of iron powder in NCG2, as a partial substitute for sand, resulted in an enhancement of its thermal characteristics under ambient temperature conditions. Specifically, at a replacement rate of 25%, a maximal increase was observed in thermal conductivity, volumetric heat capacity, thermal diffusivity, and thermal effusivity, with a percentage rise of 8.6%, 7.14%, 1.8%, and 7.987% respectively.

• Based on the experimental outcomes, it can be deduced that the introduction of uniformly arranged iron fibers enhances the thermophysical characteristics of NCG2. Notably, the addition of 2.5% fiber content produces a maximal increase in thermal conductivity, volumetric heat capacity, and thermal effusivity, with percentage10.51%, 11.73%, 10.51%, respectively. However, the thermal diffusivity value reaches saturation under these conditions.

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