EFFECT OF HEAT ON SELF-COMPACTING CONCRETE WITH PARTIAL SUBSTITUTION OF FOUNDRY SAND AS FINE AGGREGATE AND ADDITION OF PROPYLENE FIBERS

[a] Rizwan Ghafoor*, [b]Muhammad Yaqoob, [c]Muhammad Umer Malik

a: Department of Civil Engineering, UET, Taxila, Pakistan, rizwanghafoor39@gmail.com
b: Department of Civil Engineering, UET, Taxila, Pakistan. muhammad.yaqub@uettaxila.edu.pk
c: Department of Civil Engineering, UET, Taxila, Pakistan, muhammadumermalik061@gmail.com
*Corresponding author: Email ID: rizwanghafoor39@gmail.com

Abstract- Foundry sand mainly consists of silicates, and it is used as a replacement of fine aggregate to make self-compacting concrete that is cheaper, better for the environment, and sustainable. This research study looked at how at elevated temperatures foundry sand and propylene fibers (PPF) changed the mechanical properties of self-compacting concrete. 25% cement was replaced with fly ash, fine aggregate with foundry sand at different proportions (0%, 20%, 30% & 40%) and propylene fibers in 0.75% were added. The goal was to determine the mechanical properties of above-mentioned mixes of self-compacting concrete at 25ºC, 300ºC, 400ºC and 500ºC and to compare them with normal mix self-compacting concrete. The ratio adopted for the testing is of 1:1.56:2.60 (Binder: Fine Aggregate: Coarse Aggregate). For examining the mechanical characteristics of concrete the tests carried out were splitting tensile strength, compressive strength and Flexural strength tests. Experimental results show that the mix with 25% fly ash, 20% foundry sand replacement with addition of 0.75% of propylene fibers has performed better than all other samples including the control mix at all elevated temperature.

Keywords- Foundry Sand, Elevated temperature, Heat effect, Propylene fibers, Mechanical properties.

1 Introduction

Heat is natural but sometimes it becomes accidental phenomena. Thousands of structures catch fire annually. Heat reduced the strength of concrete and made the structure unsafe. Although a lot of prevention has been taken to control the fire in buildings but still, they are under process. To make a safe structure against fire up to a certain time limit is the main purpose of the following study. When a closed room catches fire then the temperature of the structural elements gets increased with time. Concrete is an important building material that is used all over the world. Concrete comprises water, cement, sand, and small rocks. Researchers are trying to encourage builders to use natural pozzolanic materials as supplementary cementing materials (SCMs). Using SCMs, the carbon dioxide's (CO2) amount releasing into atmosphere during the cement-making process can be kept to a minimum [1]. Natural pozzolans can be used instead of cement in concrete because they have unique properties like low permeability, less heat of hydration, high sulphate resistance, and an enhancement to the ultimate concrete strength [2].

This study investigates the use of foundry sand, an industrial byproduct that is a high-quality silica sand with consistent physical properties. Due to its exceptional heat conductivity, foundry sand has been used for millennia in the ferrous and nonferrous metal casting industries as a byproduct. Sand is an essential component of the casting of metal process, and foundries frequently recycle and reuse it until it is no longer acceptable, at that point it is known as "foundry sand." According to research by Siddique and de Schutter [3], up to 10 million tonnes of foundry sand are thrown away each year in the United States alone but may potentially be repurposed. In trials done by Siddique et al. [4], waste foundry sand was used to replace as much as thirty percent of the normal sand in concrete. Khatib and Ellis [5], on the other hand, substituted up to 100% of the used sand with old foundry sand and noticed a decline in strength as the foundry sand percentage rose.

By nature, concrete is brittle material, hence, to improve the ductile properties of concrete, researchers have used fiber reinforcements and other materials [6,7]. PPF are excellent polymer fibers because of its low cost, lightweight, low thermal conductivity and high modulus of elasticity [8]. Incorporating PPF into concrete can assist reduce drying shrinkage and increase compressive, flexural, and tensile strength [9,10]. Afridi et al. [11] researchers examined the mechanical properties of mortars reinforced with PPF and discovered that ductility was greatly enhanced. There was no decrease in strength up to the optimal level of 0.75% PPF.

There are different individual studies carried out to study the impact of using foundry sand as fine aggregate and polypropylene fibers on self-compacting concrete's properties, no previous study has been carried out to analyze the synergistic effect of heat on self-compacting concrete made by replacement of foundry sand as fine aggregate with addition of polypropylene fibers on the performance of concrete. This study examined the effect of heat on SCC made with foundry sand and PPF on concrete's fresh and mechanical properties.

2 Experimental Procedures

2.1 Materials with their Properties and Mix Proportions

Fly ash (FA) and ordinary Portland cement, or OPC for short, were used as the binding ingredients in this research project. OPC type 1 cement, as specified by ASTM C150, was used [12]. Locally available foundry sand was purchased from the Heavy Mechanical Complex in Taxila, Pakistan. LawrancePur and Margalla, respectively, provided the fine and coarse aggregates. 19 mm long propylene fibre was used. Tap water was used for concrete mixing and curing. The superplasticizer, Ultra-Super Plasticizer 470 was added to concrete mixtures since foundry sand and PPF make the concrete less workable. The parameters of aggregate and PPF are shown in Tables 1 and 2, whereas the parameters for fly ash and sand from foundries are shown in Table 3.

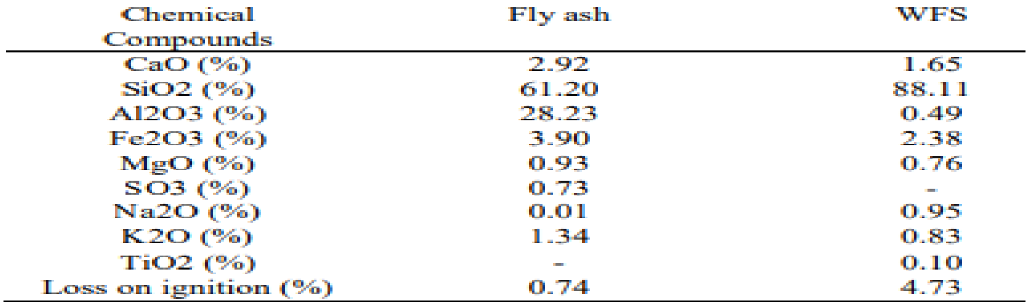
Table 1. Physical properties of fine and coarse aggregates.

Properties	Fine aggregates	Coarse aggregates
Specific gravity	2.7	2.65
Water absorption (%)	1.3	0.54
Loose density (kg/m^3)	-	1412
Rodded density (kg/m^3)	-	1550
Fineness modulus	2.99	

Table 2. Properties of Propylene Fiber.

Properties	Values
Tensile strength at breaking (MPa)	31 - 41
Flexural strength (MPa)	41 - 55
Elongation at break (%)	100 - 600
Tensile modulus (MPa)	1137 - 1551
Specific gravity	0.9 – 0.91

Table 3. Properties of Fly ash and Waste foundry sand.



Chemical Compounds	Fly ash	WFS
CaO (%)	2.92	1.65
SiO2 (%)	61.20	88.11
Al2O3 (%)	28.23	0.49
Fe2O3 (%)	3.90	2.38
MgO (%)	0.93	0.76
SO3 (%)	0.73	-
Na2O (%)	0.01	0.95
K2O (%)	1.34	0.83
TiO2 (%)	-	0.10
Loss on ignition (%)	0.74	4.73

The experimental schedule is shown in Table 4, which consists of comparing nine different mixes. M1 denoted the control mix having OPC as the only binder, while M2, M3 and M4 denoted the mixes containing 20%, 30% and 40% foundry sand as fine aggregate replacement respectively. Poly propylene fiber was also added in 0.75% in M2, M3 and M4 respectively.

Table 4. Mix Composition

Mix	Mix Type	Temperature (°C)	Cubes (28 days)	Beams (28 days)	Cylinders (28 days)
M1	Control Mix (SCC)	25	3	3	3
M1	Control Mix (SCC)	300	3	3	3
M1	Control Mix (SCC)	400	3	3	3
M1	Control Mix (SCC)	500	3	3	3
M2	OPC+20% F.S.W+0.75% PPF	25	3	3	3
M2	OPC+20% F.S.W+0.75% PPF	300	3	3	3
M2	OPC+20% F.S.W+0.75% PPF	400	3	3	3
M2	OPC+20% F.S.W+0.75% PPF	500	3	3	3
M3	OPC+30% F.S.W+0.75% PPF	25	3	3	3
M3	OPC+30% F.S.W+0.75% PPF	300	3	3	3
M3	OPC+30% F.S.W+0.75% PPF	400	3	3	3
M3	OPC+30% F.S.W+0.75% PPF	500	3	3	3
M4	OPC+40% F.S.W+0.75% PPF	25	3	3	3
M4	OPC+40% F.S.W+0.75% PPF	300	3	3	3
M4	OPC+40% F.S.W+0.75% PPF	400	3	3	3
M4	OPC+40% F.S.W+0.75% PPF	500	3	3	3
	Mechanical Testing		Compressive Strength	Flexural Strength	Split Tensile Strength

2.2 Concrete Mixing

Every batch of concrete was mixed in three steps. In the initial phase, aggregates and binders were combined dry. In second phase, more than half of water was added to create a uniform mixture, while the part of water remained, along with superplasticizer were then added. PPF was incorporated in the end to avoid the clumping of fibers due to more revolutions of mixer.

2.3 Specimen and Testing

During the casting of samples, one layers of concrete were applied to every sample. Using ASTM C1611 procedure, the self-compacting concrete slump flow was determined prior to specimen casting [13]. For determination of mechanical characteristics of concrete samples Compressive strength test, splitting tensile strength test, and flexural strength tests were done. Based on BS standard EN-12390 [14], 150mm x 150mm x 150mm cube specimen were casted, and then tested for compressive strength after being cured for 28 days.

After 28 days of curing, 150mm x 300mm concrete cylindrical samples were tested for the split tensile strength in accordance with ASTM C496 criteria [15]. The beam specimens measuring 100mm x 100mm x 500mm were tested for flexural strength in accordance with ASTM C78 specifications [16]. The test setup for these mechanical properties is given in Figure 1.

a) b) c) d)

Figure 1 Testing formation for (a) Slump flow test (b) compressive test (c) split tensile test (d) flexural test

3 Research Methodology

Four types of mixes were prepared in Laboratory. Slump flow test was conducted firstly to determine the fresh properties of SCC, then to find out the mechanical properties' compressive strength test, flexural test and split tensile strength were done in the laboratory after 28 days curing in water tank at normal temperature. After that sample of all the mixes were taken to the oven for heating at 300ºC, 400ºC and 500ºC for two hours. After getting cooled, these samples were taken to the Laboratory for the determination of their mechanical properties.

4 Results

4.1 Slump Flow

The workability of all the mixes was determined using slump cone apparatus based on procedure given by ASTM C1611. To create workable mixtures, varied amounts of superplasticizer were combined with a consistent water-cement ratio. Figure 2 displays the results of the workability of each mixture. The mix M2, M3, and M4 which has percentage of Foundry sand, fly ash and propylene fibers produced somewhat lower slumps than the control mix (M1). The reduction in mixes workability can be related with fineness of foundry sand as it more fine than fine aggregate. The addition of PPF to the mixtures has also significantly decreased their workability because the concentration of fibers enhances internal friction in mixtures with a constant amount of water added.

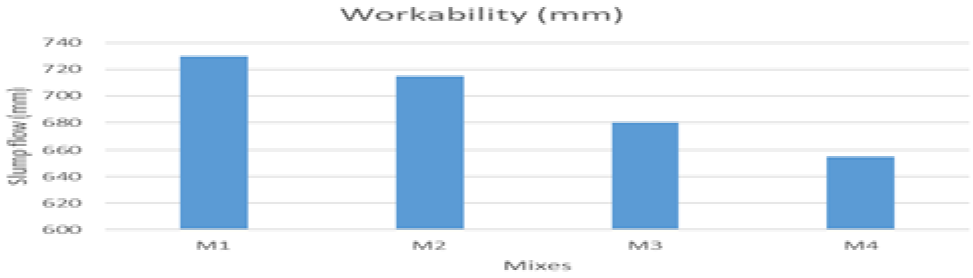


Figure 2: Slump Flow Test

4.2 Compressive Strength

According to Figure 3, which illustrates the compressive strength measurements for all the mixes, the results demonstrate that incorporating foundry sand led to enhanced compressive strength properties after a 28-day curing period. Specifically, for mixture M2, the compressive strength increased by 2.87%, 7.68%, 12.42%, 16.20% at 25ºC, 300ºC, 400ºC and 500ºC respectively, in comparison with the mix (M1) that is control mix. The enhancement in strength can be accredited to the formation of additional cementitious compounds from the pozzolanic reaction, fineness of foundry sand as well as the filler properties of fly ash, and addition of PPF to contract cracks. These properties result in a more tightly packed and finer microstructure for the concrete. The acquired results indicate that these samples performed better than control mix self-compacting concrete samples at elevated temperatures.

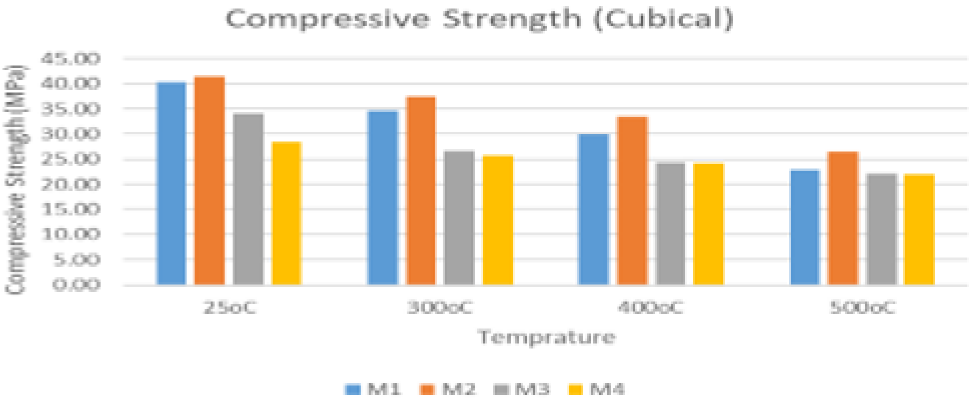


Figure 3 Compressive Strength Test

4.3 Split Tensile Strength

Figure 4 displays the split tensile strength values for all the mixtures. Following a 28-day curing period, it can be observed that the mixtures incorporating foundry sand exhibited superior performance compared to the controlled mix at elevated temperatures. Specifically, for mix M2, the splitting tensile strength increased by 3.48%, 21.38%, 21.25%, 11.89% after 28 days at 25°C, 300°C, 400°C and 500°C respectively, in comparison to mix M1. These results indicate that the inclusion of foundry sand positively influenced the split tensile strength of the concrete samples, particularly at higher temperatures. The increase in split tensile strength could possibly be explained by the coarse texture of the fibers, which enhances the adhesion and bonding between the concrete and the fibers. On the onset of cracking in concrete, the fibers begin to arrest the crack propagation due to their bridging impact, reducing the brittleness of the concrete and boosting its post-cracking behavior.

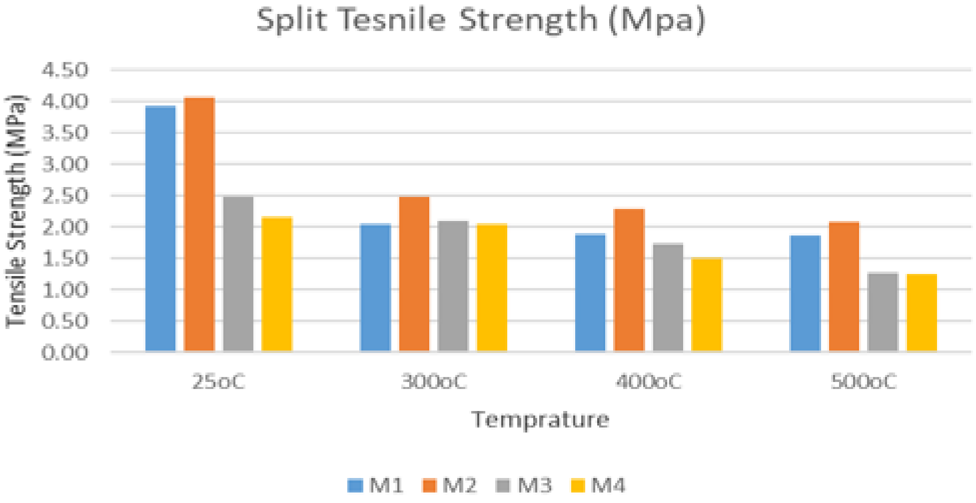


Figure 4 Split Tensile Strength Test

4.4 Flexural Strength

Figure 5 depicts the concrete's flexural strength of all specimens. Using foundry sand in self-compacting concrete enhanced flexural strength after being cured for 28 days. M2, M3 and M4 boosted the strength by 8.11%, 2.27% and 12.12% and 12.50% at 25°C, 300°C, 400°C and 500°C respectively when compared to the control mix (M1). The enhanced flexural strength results from the adherence of PPF fibers to the matrix and the enhanced bond quality, which prevents crack propagation. The incorporation of randomly mixed fibers resulted in an improvement of crack resistance, which can be attributed to the bridging effect. This effect, in turn, led to an increase in ductility and flexural strength.

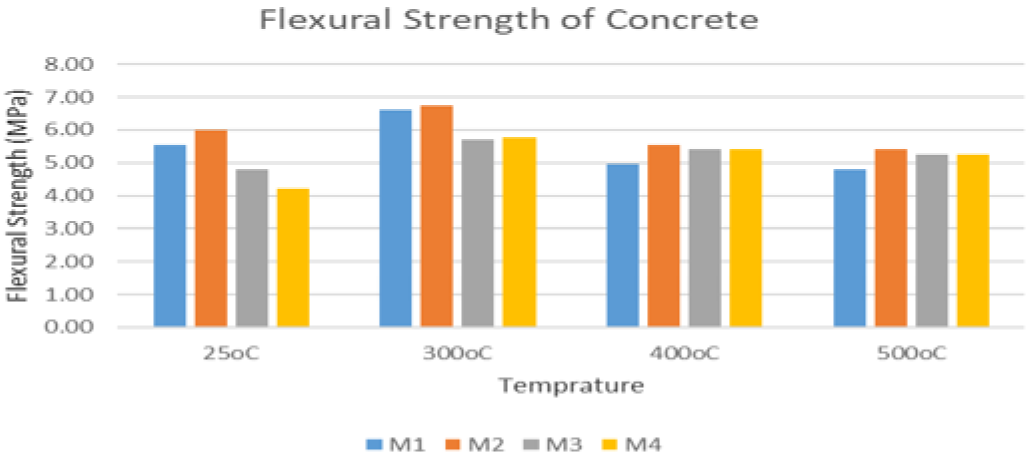


Figure 5 Flexural Strength Test

5 Conclusions

Based on the conducted experimental study, the study's findings lead to the following conclusions:

1- The workability of foundry sand incorporated mixes was lowered, while incorporation of Propylene fibers caused in further decrease of workability.

2- The addition of foundry sand as fine aggregate enhanced the mechanical characteristics (flexural, split tensile and Compressive strengths) of concrete.

3- By addition of 25% fly ash, 20% foundry sand as fine aggregate with addition of 0.75% propylene fibers in SCC formation, the mechanical properties like compressive, flexural and tensile strength at 25°C has been increased by 2.87%, 8.11%, and 3.48% respectively.

4- While at 300°C, the mechanical properties like compressive, flexural and tensile strength have been increased by 7.68%, 2.27%, and 21.38% respectively.

5- While at 400°C, the mechanical properties like compressive, flexural and tensile strength have been increased by 12.42%, 12.12%, and 21.25% respectively.

6- While at 500°C, mechanical properties like compressive, flexural and tensile strength have been increased by 16.2%, 12.50% and 11.89% respectively.

7- The incorporation of high dosage 30% and 40% of foundry sand content resulted in degradation of the mechanical characteristics of self-compacting concrete.

Acknowledgment

The authors express their sincere gratitude to all individuals and departments who provided support throughout the research process. Special thanks are extended to the Civil Engineering and Industrial Departments of UET Taxila, as well as Engr. Dr. Muhammad Yaqoob for their invaluable contributions and to my parents and friends for their support.

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