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A swarm intelligence shrinkage optimization of fly ash and tile aggregate based self-compacting concrete exposed to high temperatures

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Abstract

Almost all the building structure is built with the basis of Self-compacting concrete (SCC). Hence, it has increased the researcher's interest in enriching the mechanical properties by optimizing the shrinkage. At the elevated temperature, the cause of shrinkage measure was very high. To overcome this issue, a novel intelligent African Buffalo-based Shrinkage Diminution (ABbSD) has been developed mathematically to optimize the shrinkage strain on concretes. In addition, the SCC-M40 and SCC-M50 were the grades selected for this research. Also, broken tile aggregates and fly ash were partially replaced at 0%, 10%, 20%, 30% and 40% and 0%, 10%, 20% and 30% by coarse aggregate mass and cement, respectively. Moreover, the hardened concrete properties were measured to determine the optimum mix of the concrete specimen. Also, to determine the optimum specimen's strength at elevated temperatures, concrete specimens were heated at 100 to 250 degree Celsius for 2hrs and 4hrs. Henceforth, the performance parameters like compressive strength, split tensile, shrinkage, and flexural strength were measured. Then the shrinkage parameter values are then given as the optimization algorithm's input. Moreover, the African buffalo fitness function is activated to tune the performance parameters to the desired level. Consequently, the comparison was performed to determine the prepared optimum concrete specimen's effectiveness. The result demonstrated that the developed specimen has higher strength than other SCC specimens. Hence, the recorded shrinkage reduction rate by the proposed model is 38 to 40%. In addition, the compressive strength of M-4 and P-3 at 28 days is 43.37 N/mm^2 and 50.97N/mm^{2,} and the recorded compressive Strength for M-4 and P-3 at 90 days is 50.38N/mm^2 and 60.69N/mm^2 respectively which is quite high compared to other models. It is considered as the advantage of the proposed model over other studies.

Keywords: Broken tiles, Fly ash, Self-compacting concrete, Fresh properties, Hardened properties, M40 and M50 Grade

1. Introduction

Concrete is a combined material produced with coarse and fine aggregate, water, and cement materials used in different quantities [1]. In a volume of concrete, three-fourths were obtained from aggregates [2]. Moreover, based on the cement paste properties, the performance of the cement is measured; the active constituent of concrete is cement [3]. For concrete production, Portland cement was normally utilized [4]. Furthermore, the required strength of concrete was based on concrete grades [5]. Generally, the compressive strength of M40 and M50 grade concrete was 40 N/mm^2 and 50 N/mm^{2,} respectively [6]. The M50 grade concrete was used in high-strength concrete structures, and the M40 grade was used in commercial construction areas for designing beams and foundations [7]. Subsequently, the M40 grade has high durability and can withstand chemical-based corrosion [8]. The concrete mix ratios depend on the proportions of the concrete components such as sand, water, aggregate and cement; it was an important factor in evaluating the concrete structure's compressive strength [9]. So, the researchers have continuously made efforts to create different types of concretes [10]. Due to the increase of growth and time in the construction sector, various kinds of concrete were developed; for instance, concretes with high strength, self-compacting, self-healing and high performance were used [11]. In many countries, Self-Compacting Concrete (SCC) is used in concrete construction because it increases the reliability and durability of structures [12]. Also, in construction sites, it reduced the need for skilled labourers [13].

Moreover, it was an advanced form of NVC (Normally Vibrated Concrete) because it reduced noise pollution and was flexible in designing complicated shapes [14]. Also, SCC was very useful in filling the spaces in heavy structural elements like columns, beams, shear walls, slabs, and foundations [15]. However, it passed through more bulk materials than normal concrete [16]. However, the recovery of waste byproducts from industries for utilization in construction materials was now a widely accepted solution to reduce the environmental impacts and landfill site waste dumping [17]. The waste materials with pozzolanic properties can substitute in cement, and replacing natural aggregates with industrial waste byproducts in concrete was a good strategy for reducing the waste materials [18]. Moreover, during transportation, many tiles were broken and not reused; for this, the broken tiles effect was evaluated and determined the construction material design for proper mix in concrete [19].

To control the hardening properties of SCC, a combination of various powdered materials was used [20]. SCC was a hugely workable concrete, and the mixing composition was the same as the vibrated concrete [21]. Moreover, fly ash or limestone fillers were

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utilized as a partial replacement for cement to avoid the unrestrained generation of heat [22]. During the casting of reinforced concrete structures, adequate compaction was the primary requirement [23]. In addition, inadequate concrete compaction reduced durability and strength and created voids in concrete structures. SCC on designs has good Workability, and it was adopted in inaccessible situations to handle mechanical compaction such as columns, submerged concreting and beam concrete [24]. Moreover, it has a large flowing ability and can fill the formwork. The SCC compressive strength is larger than conventional vibrated concrete due to the packing effectiveness of filler; the porosity was reduced [25]. The exclusion of vibration in concrete shortens the time of construction, reduces the cost of equipment and labour, and improves productivity [26]. The most commonly used mineral admixture in SCC is lime and fly ash. It improved the packing of the particle by filling the pores among cement grains [27].

SCC plays a vital role in construction because of its qualitative and quantitative utility [28]. The fly ash addition in cement improved the concrete's quality and durability [29]. Also, the other name of SCC was self-consolidating concrete; normally, it was made with modifying viscosity admixtures and superplasticizers [30]. For proper filling of formwork, filling and passing abilities were required to maintain good homogeneity [31]. The mixed proportions of SCC were different from ordinary concrete and environmentally friendly [32]. Moreover, there was a lack of globally accepted standards and diverse design tests; the material selection was more stringent [33]. Furthermore, to increase the concrete durability, many methods were introduced, such as fly ash and granite waste as a partial replacement [34], fly ash and alccofine in concrete [35], compressive stress optimization of SCC using Vipulanandan p-q Model [31], Multiscale method for compressive strength prediction [32], Chemical resistant SCC [33], Characterization of SCC mechanical properties [36], soft computing models to predict SCC compressive strength [37] and the compressive strength of concrete using surrogate[38]. But still, there is no effective solution for high-strength SCC. These issues have motivated this research towards substituting coarse aggregate and cement with broken tile and fly ash. The motive of this present research work is that the SCC in concrete structures improves the quality, reliability and durability due to its homogeneity and better concrete compaction [39]. In the construction industry, it improves the productivity and condition of working; eliminates the problems based on vibration [40]. However, all those SCC mixes reported high shrinkage rates at elevated temperatures [41]. These issues have motivated this research towards replacing cement and coarse aggregate with fly ash and broken tile.

Thus, the current research has aimed to develop a high-strength SCC with less shrinkage. In addition, the key novelty in this paper is the usage of the African buffalo algorithm for the mix selection process, which has reduced the shrinkage rate. The main significance of this study is selecting the proper mix selection for strong buildings. The key parameter considered for this valid mix selection is shrinkage reduction. Hence, to choose the appropriate optimal mixes, the optimal desired shrinkage rate is fixed in the finest solution of the buffalo algorithm. During the mix selection process, the algorithm function was iterated continuously till the optimized shrinkage was found. If the optimized shrinkage is found, the process is stopped, and the mix levels are noted. Finally, all performance parameters were validated for the selected optimal mixes, and the comparison was made with past studies.

The key contribution of the present research is summarized as follows,

- The prepared M40 and M50 grade concrete samples are taken for this study to evaluate the shrinkage reduction function
- Then an intelligent African Buffalo-based Shrinkage Diminution (ABbSD) was developed to optimize the large shrinkage in concrete samples by selecting the optimum mix.
- The optimum mix concrete is cured for 28 to 90 days; after curing the concrete, it is kept free for 24hrs, and the concrete samples were heated at elevated temperatures of 100, 150, 200, and 250 degrees. The time of exposure for each temperature is 2hrs and 4hrs, respectively.
- At last, the effectiveness of the present study is evaluated by comparing the current work with other existing results in terms of tensile strength, compressive strength and flexural strength.

The rest of the paper is sketched out as follows. Some recent works related to this research are described in Section 2. In Section 3, the experimental programs are explained. Section 4 explains the proposed method of SCC-M40 and SCC-M50 grade concrete. Section 5 covers the presented method test results and comparison with other SCC mixes. At last, in Section 6, the concluding remarks are exhibited.

2. Related work

Some recent literature related to the present work is described below:

To solve the problems of high energy consumption and emission of carbon dioxide, active alkali binders with geopolymer were introduced as an alternative to ordinary Portland cement. In worldwide construction sectors, the durability of concrete was a vital concern, and the durability interpretation of concrete was improved by replacing recycled industrial and agricultural wastes, which are environment-friendly. Hussein and Shah [15] examined the effectiveness of self-compact active alkali concrete durability performance by fly ash as a substitute material in concrete. The concrete properties like compressive strength, the ability to fill and pass, and drying shrinkage were measured. As a result, the replacements of GBFS by fly ash reduced emissions CO_2 and attained a healthier environment. Furthermore, it creates cracks on the surface of the concrete.

Agwa et al. [16] presented a paper about lightweight SCC (LWSCC) microstructure and mechanical properties incorporated with CSA (cotton stalk ash) and RSA (rice straw ash) as a substitute for cement content. The fresh LWSCC segregation resistance and passing and filling ability were measured, and the hardened LWSCC mechanical properties split tensile Strength and compressive Strength was measured. The results show that the hardened properties increased as the CSA and RSA percentages increased. Moreover, an increase in the ratio of both CSA and RSA decreased Workability. An increase in water hardens the concrete.

The partial substitution of admixtures in concrete has increased its strength and durability. The SSC does not need vibration to spread the concrete in densely reinforced and thinner sections. Jain et al. [17] have presented research based on SSC sustainable development using fly ash and granite waste as an alternative for cement and sand, respectively. The hardened concrete properties were appraised using flexural Strength, compressive Strength, and ultrasonic pulse velocity tests. In contrast, the concrete's fresh properties were appraised using L-box tests, V-funnel, J-ring, and slump flow tests. The study of this research indicated that the combined use of granite waste and fly ash in SCC could enhance the hard and fresh properties. However, granite waste has some negative effects on the Workability of concrete.

In concrete, cement was the most important constituent. Manufacturing cement on an enormous scale consumes high energy and liberates detrimental products. Directing on industrial reuse and recycled waste materials for cement replacement in concrete improves sustainable construction. It reduces greenhouse gases, Kavyateja et al. [18] have researched the fragmentary substitution of fly ash and alccofine in concrete. The substituted material was analyzed through SEM (Scanning Electronic Microscopy) analysis, Fourier infrared spectroscopy, X-ray diffraction, and thermogravimetric analysis. SCC fly ash, and alccofine addition showed a remarkable improvement in analytical methods. Moreover, the alccofine in concrete made the concrete more hardened.

To increase the content of RCA (recycled concrete aggregate) and SCM (supplementary cementitious material) by utilizing fly ash, slag, and silica fume combination, Guo et al. [19] proposed a sustainable SCC by substituting cement with SCM and natural aggregates of RCA. The binary, quaternary and ternary mix of 23 mixes was prepared. The durability and mechanical properties were evaluated, and the effectiveness of SCM and RCA was investigated. The proposed combination of constituent test results shows that it improves RCA's durability and mechanical properties with SCC. Also, it optimizes the SCC sustainability performance by mitigating the content of natural resources and cement. Moreover, an increase in RCA causes adverse effects.

3. Experimental program

In this section, the selected materials, materials testing, mix proportions, and fresh and hardened properties of concretes are described as follows. Based on the mix proportions and material selection, the strengths of the concrete were increased.

3.1 Materials

In this work, 53 grade OPC (ordinary Portland cement) validated to Indian Standard Specifications IS: 12269-1987 is used and tested as per IS: 8112-1989 [39]. The OPC provides high durability and strength to structures due to its higher grade crystallized structure and size of particle distribution as optimum. Table 1 shows the test result of 53 grade OPC.

Table 1 Test results of cement

Description of test	The test result of 53 grade OPC
Specific Gravity	3.09
Fineness modulus	7.8%
Setting time- initial	81 minutes
Standard consistency	29%
Setting time- final	275 minutes

The 53-grade OPC is high-strength cement and is commonly used for high-strength applications. The required compressive strength attained at the 28days is indicated as a grade. Fly ash is a byproduct; chemically, it is a pozzolan. In concrete, fly ash is partially substituted with cement, increasing stability and durability. The fly ash is tested as per IS: 3812-1981, and in concrete, two types of fly ash were commonly used, i.e. Class F and Class C. Class F fly ash is used in this work because it has low calcium, and it easily interact with cement. Moreover, in large construction projects, nearly 10% of tiles were wasted and can be used as a coarse aggregate and in transportation, many tiles were broken and reused. The broken tiles were partially replaced in coarse aggregate with a size of 20mm. The 20mm coarse aggregate is utilized and tested as per IS: 383-1970 in this work. In this work, river sand is used, and the river sand is tested as per IS: 383-1970. The advantage of river sand is dust-free and has a size of less than 4.75mm; the shape of river sand is cubical and used in this work. In high-strength concrete, additives are known as Superplasticizers and water reducers in a large range. Moreover, adding contrast SP 430 in concrete improves concrete's flowability, durability, and strength. The water in the concrete is a lubricant for both coarse and fine aggregates, making the mixing workable. In concrete, the amount of water controls the fresh and mechanical properties. Impure water reduces the long-term strength of concrete.

3.2 Materials testing

The fine, coarse, and broken tile aggregate and fly ash are tested to find the specific gravity, fineness modulus, and water absorption. The materials are tested as per IS standards, and the test of materials are described below:

3.2.1 Sieve analysis

The test conducted to find the size of particles of both fine and coarse aggregate is known as the Sieve analysis test. The collected aggregates are completely sieved by a suitable IS sieve to measure the particle size. In construction work, the sieve analysis helps to select the proper size of aggregates. The test result of weight retained in increased percentage on the sieve is shown in Table 2.

Table 2 Test result of materials

Materials	Cumulative percentage weight retained	Fineness modulus (FM)	Specific gravity	Water Absorption (%)
Fly ash	119.5	1.195	2.45	-
Fine aggregate	272	2.72	2.61	1.98
Broken tile aggregate	730.64	7.306	2.33	1.15
Coarse aggregate	735.82	7.358	2.78	1.033

The standard IS: 383-1970 sieve size for fine aggregate was 4.75mm, 1.18mm, 2.36mm, 150micron, 300micron, and 600micron, and for coarse aggregate was 80mm, 20mm, 10mm, 40mm and 4.75mm, arranged in descending order.

3.3 Mix proportions

The mixtures of SCC were divided into two grades, M40 and M50. In this investigation, fly ash, and broken tile aggregates were partially replaced at 0%, 10%, 20%, 30% and 40% and 0%, 10%, 20% and 30% by coarse aggregate and cement mass, respectively. Moreover, these mixes were used to identify the concrete mixture's rheological properties. The conplast SP 430 was adjusted in all combinations to acquire the proper flowability without segregation. Moreover, the mix percentages were selected in unequal intervals in existing compounds, and the superplasticizer dosage was the same for all. It reduces the flowability of concrete in mixes, and the variations in strengths are not similar. Hence, this study selects equal intervals of mix percentages, and the superplasticizer dosage is adjusted for every mix. Adjusting the superplasticizer's dosage improves the flowability of every mix.

From the acquired results of material testing, the mix design is prepared as per recommended procedure by the committee of EFNARC [26], and the obtained mix proportion by weight is 1:1.26:1.47 (cement: coarse aggregate: fine aggregate) with a 0.44 water-cement ratio. Here, SP is the superplasticizer. The quantities obtained per EFNARC standards of M40 and M50 grade concrete are shown in Table 3. In the mixing of concrete, when a uniform mix is received, the superplasticizer is added.

Table 3 SCC-M40 and SCC-M50 mix proportions

Grade	Mix. no	Mix (%)	SP (%)	Water (kg/m^3)	Fly ash (kg)	Fine aggregate (kg/m^3)	Coarse aggregate (kg)	Cement (kg)	Broken tile aggregate (kg)
	M-1	0- fly ash 0-broken tile	1.5	200	0	724.746	720	490	0
	M-2	10- fly ash 10-broken tile	1.1	200	49	724.746	648	441	72
M40	M-3	20- fly ash 20-broken tile	1.4	200	98	724.746	576	392	144
	M-4	30- fly ash 30-broken tile	1.4	200	147	724.746	504	343	216
	M-5	40-fly ash 40-broken tile	1.2	200	196	724.746	432	294	288
	P-1	0- fly ash 0-broken tile	1.3	200	0	774.107	756	500	0
	P-2	10- fly ash 10-broken tile	1.5	200	50	774.107	680.4	450	75.6
M50	P-3	20- fly ash 20-broken tile	1.4	200	100	774.107	604.8	400	151.2
	P-4	30- fly ash 30-broken tile	1.2	200	150	774.107	529.2	350	226.8

4. Proposed ABbSD

The rapid development of partial replacement of admixtures in concrete has fashioned a great demand for SCC in the construction sector. In this current research, the component of mineral admixture fly ash and coarse aggregate broken tile was taken to test the strength of concrete. The combination of broken tile and fly ash improved the durability of concrete in self-compacting concrete. It is helped to find the optimal shrinkage rate then the specific mix selection for the reduced shrinkage rate has been considered the optimal mix.

The concrete's hardened and fresh properties measure SCC's Strength, loading capacity and flowability. Subsequently, the shrinkage developed in SCC was reduced by a developed intelligent African Buffalo-based Shrinkage Diminution (ABbSD). Finally, the strength and durability of the concrete were evaluated by testing the prepared concrete cube. The proposed ABbSD is shown in Figure 1.

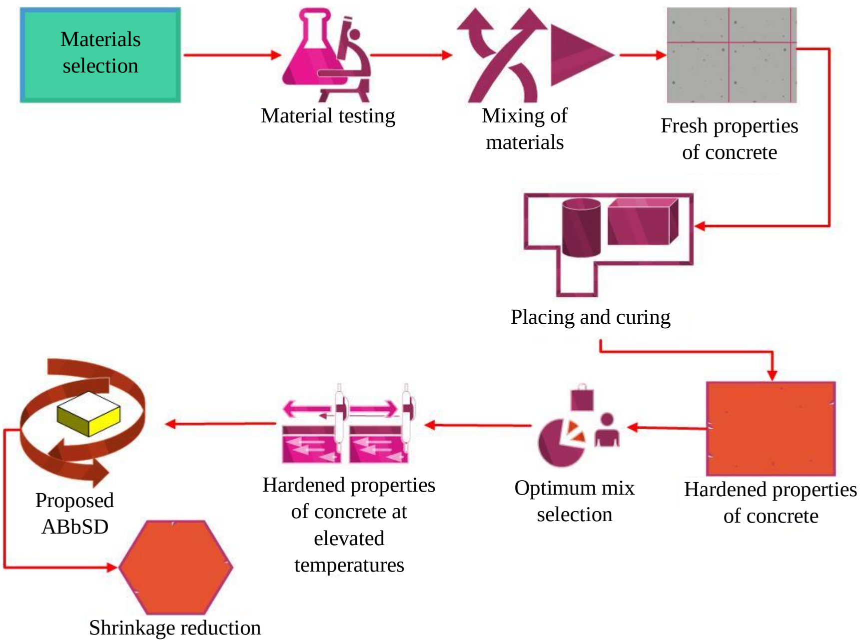

Figure 1 Proposed ABbSD

4.1 Process of proposed ABbSD

The ABbSD is developed to optimize the shrinkage strain on concrete in this work. The developed model is based on African Buffalo Optimization (ABO) [22], and it was based on shrinkage diminution. In this process, the Buffalo reduces the shrinkages developed in concrete after the curing period. The dry shrinkage at days [21] is determined by eqn. (1),

$$\delta_{S(x)} = \frac{x}{57.4 + x} 2.358\delta_{s(28)} \tag{1}$$

Where $\delta_{s(x)}$ represents shrinkage at x days, x denotes the time in days and $\delta_{s(28)}$ denotes the laboratory test shrinkage value at 28 days. The fitness value [28] of shrinkage is reduced using eqn. (2),

$$j_{.\mu} + 1 = j_{\mu} + l_1 x_1 \left(r_{g\max.\mu} - \delta_{s(x)}\right) + l_2 x_2 \left(r_{p\max.\mu} - \delta_{s(x)}\right) \tag{2}$$

Where $j_{.\mu} + 1$ represents the reduction of shrinkage, $j_{.\mu}$ denotes the initial stage of shrinkage at 7 days of curing, the co-efficient of cement for type 3 grade is represented as $l_1 x_1$ and $l_2 x_2$, $r_{g\max.\mu}$ and $r_{p\max.\mu}$ represents the best shrinkage. The pseudocode of the proposed method is detailed in algorithm 1 and flow diagram of ABbSD is described in Figure 2.

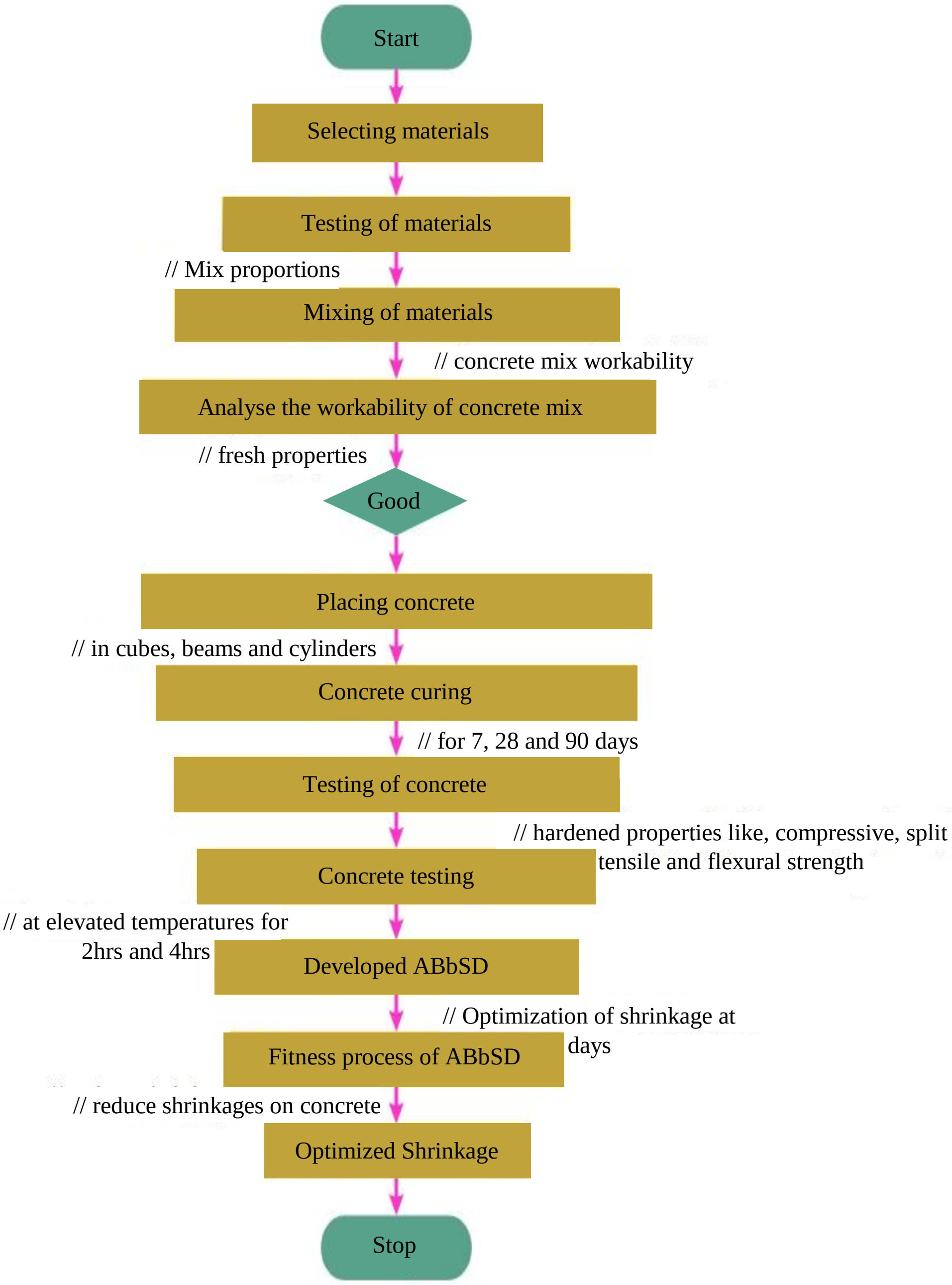

Figure 2 Flow diagram of ABbSD in optimization of concrete shrinkage

The effectiveness of the concrete is evaluated concerning strengths like compressive, flexural and split tensile. The concrete attains higher strength suitable for construction.

Algorithm: 1 Concrete specimen and proposed ABbSD

Start
{
Testing of materials
Mixing of materials ***// Workability of concrete mix***
Analyze the concrete mix workability
If concrete Workability $\rightarrow$ *is good*
Then
Placing concrete
Curing concrete
Evaluate*: Concretes hardened properties*
//compressive, split tensile and flexural strength
Testing of concrete ***//elevated temperatures***
Develop ABbSD ***// optimize the shrinkage***
Consider the developed concrete as S
int S = M-1, P-1, ***//initialize the concrete beam***
where S is the concrete beam
Calculate the shrinkage strain on days
*Compute_* $\delta_{s(x)}$ *using eqn. (1)* ***// shrinkage on days***
Calculate the reduction of shrinkage
*Compute_* $j_{.\mu}+1$ *using eqn. (2)* ***// fitness function***
For all *S*= $j_{.\mu}+1$
Here $j_{.\mu}+1$ *is the fitness process of ABbSD* ***//optimize the shrinkages in concrete***
}
Stop

5. Results and discussion

The developed ABbSD method was simulated and implemented in MATLAB R2020a, running on the windows 10 platform. In addition, the main objective of this work is to optimize the large shrinkages developed in the concrete surface. Moreover, shrinkage was an important parameter in determining concrete durability. An effective ABbSD model was proposed in this research to reduce the shrinkages.

5.1 Case study

In this research, the concrete specimens are made by SCC-M50 grade with coarse aggregate and cement was partially replaced with broken tiles and fly ash. The concrete materials are tested to determine the FM, water absorption and specific gravity. From these results, the mix proportions are evaluated to mix the concrete with an adequate amount of water. At first, the concrete mix is tested to assess the flowability and the result of SCC-M50 grade with 20% partial replacement of broken tiles and fly ash in coarse aggregate and cement is shown in Table 4. This test determines the concrete volumetric contraction due to moisture loss. The co-efficient of cement for type 3 is 1.10 as per ACI 209 [29].

Case 1: Fresh properties

In this study, T_{50} slump flow, L-box, slump flow, and V-funnel tests for fresh SSC mix were conducted in compliance with EFNARC standards. The fresh properties of SCC play a vital role in Workability and mechanical interpretation, and the fresh concrete properties [40] are described as follows:

Slump flow: It has been developed to measure the concrete's horizontal flow at the dereliction of barriers. This test is a recurrently used method, and in filling ability, it gives a good evaluation. It also indicates the segregation resistance. The slump cone of base and top diameter of 200mm and 100mm, respectively, and 300mm height was used. The flow value was higher for SCC because it has a large capacity to fill the mould with its weight. As per EFNARC, the standard range of test results should be 650mm to 800mm. For the slump flow test, 6 litres of concrete was required. During this test, the bleeding and segregation of aggregate were inspected visually.

T_{50} *Slump flow test:* The method of this test is the same as the slump flow test standard EFNARC. It determines the time taken to reach the 500mm mark for the concrete, and time is known as T_{50} time. In this test, the lower time designates the flowability as greater. The test result T_{50} slump flow of M40 grade and M50 grade concrete with different mixes is shown in Table 4. The standard T_{50} time is 2-5 seconds.

V-funnel test: It evaluates the SCC's filling ability and viscosity with 20mm size aggregate. This test requires 20 litres of concrete filled in the funnel to assess the flow time of concrete. After this, concrete is refilled in the funnel and left to settle for 5 minutes; if there is segregation, then flow time increases. As per EFNARC, the standard test result range is 6-12 seconds. The indication of flow time as shorter has greater flowability.

L-box test: This test is utilized to find the concrete's passing ability through reinforced or confined areas. The standard range of test results was 0.8 to 1.0 per EFNARC standards. To perform this test, 14 litres of concrete was needed. The apparatus is L-shaped, with horizontal and vertical sections segregated by a movable gate. The concrete is filled in a vertical box area, and the gate is lifted to flow the concrete in the horizontal section. After the flow is stopped, the flat section height of the concrete is expressed as a portion remaining in the vertical section. The box's horizontal section is marked at 400mm and 200mm from the gate and measures the time taken; the time is known as T40 and T20.

Table 4 Test results of M40 and M50 grade fresh properties for different mix

Grade of concrete	Mix. no	The test result of L-box (H2/H1)	Slump flow test result (mm)	The test result of T_{50} Slump flow (sec)	The test result of V-funnel (sec)
M40	M-1	0.86	670	4	12.43
	M-2	0.85	680	3.95	10.8
	M-3	0.84	687	3.47	8.90
	M-4	0.825	690	3.2	8.67
	M-5	0.815	650	4.03	8.32
M50	P-1	0.87	700	4.53	12.47
	P-2	0.855	710	4.35	11.6
	P-3	0.83	725	3.9	9.7
	P-4	0.81	705	4.2	8.63

The fresh properties of SCC play a vital role in Workability and mechanical interpretation. To evaluate the fresh concretes slump flow test was conducted. The results of the slump flow test, V-funnel test and L-box test are detailed in Table 4. The SCC with different percentages of superplasticizer increased the flowability. The M-5 mix and P-4 mix has lesser filling and flow ability than other mixes. The slump flow of M40 grade concrete M-4 gave a greater flowability of 690 mm; in M50 grade concrete, the P-3 mix has a high flowability of 725mm. The T_{50} slump flow test result of M40 grade concrete with M-4 mix has a less time of 3.2 seconds; in M50 grade concrete, the P-3 has less time of 3.9 seconds. Hence, it has greater flowability. The V-funnel test result indicated that M40 grade concrete with M-4 mix takes 8.67 seconds for concrete flow, and M50 grade concrete with P-3 takes 9.7 seconds for concrete flow. The L-box test result of the M40 grade with M-4 mix attains a blocking ratio of 0.825, and the M50 grade with P-3 has a 0.83 blocking ratio.

Case 2: Placing and curing

The concrete with different mixes is placed in cubes of standard size $15cm\times15cm\times15cm$, beams of size $10cm\times10cm\times50cm$ and cylinders of size $15cm\times30cm$. After placing the concrete on specimens in moist air, the test specimens are stored at 27°C for 24hrs until demolding. After drying, from the moulds, the samples were removed and submerged in clean water. The period of curing was 7, 28 and 90 days. After the specified time of curing, the specimens were removed, and the excess surface water was eradicated. After curing, the M40 and M50 grade concrete is tested to determine the strengths and optimum mix.

Case 3: Tests on hardened concrete

After the curing process, the concrete is tested to determine the concrete specimen's strengths by EFNARC [40]. To determine the optimum mix replacements, all mix specimens' average flexural, split tensile and compressive strengths were measured at 7, 28 and 90 days. Furthermore, the optimum mix replacement of concrete was determined based on hardened test results. In existing works, the dry shrinkage tests were performed for 28 and 90 days, but in this study, the shrinkage tests were conducted for 7, 28 and 90 days for better results. Moreover, in the concrete mix, the partially replaced cement and coarse aggregate by fly ash and broken tiles play a vital role in improving the concrete's hardened properties.

Based on the test result of concrete specimens, the optimum mix replacement was the M-4 mix; the M-4 mix has higher strengths than other concrete mixtures. The obtained test result of SCC-M40 grade concrete mixture strength is shown in Table 5.

Table 5 SCC-M40 Hardened properties

Mix. no	M-1			M-2			M-3			M-4			M-5		
Age of curing (days)	7	28	90	7	28	90	7	28	90	7	28	90	7	28	90
Compressive Strength (N/mm^2)	32.58	40.75	48.28	34.95	41.6	49.27	37.4	42.6	50.5	39.62	48.7	53.5	36.24	40.75	42.1
Flexural Strength (N/mm^2)	6.25	7.432	7.598	7.28	7.44	8.75	7.3	7.6	7.82	7.64	8.25	9.85	5.25	5.79	6.3
Split tensile Strength (N/mm^2)	2.247	3.318	5.232	2.53	3.575	4.7	2.730	3.746	5.1	3.8	4.2	6.9	3.85	3.27	4.8
Shrinkage strain ($\times10^{-6}$)	242.5	357.25	435.98	250.7	367.47	455.32	286.4	379.5	500	248	325.9	486.5	493.75	527.38	556.79

From the test results, the optimum mix replacement was the P-3 mix; the P-3 mix has attained higher strengths by replacing fly ash and tile aggregate. The M-4 and P-3 mix has attained higher compressive, split tensile and flexural strengths due to the partial replacement of fly ash in cement and broken tiles in coarse aggregate. Moreover, the obtained test results of SCC-M50 grade concrete mixtures are shown in Table 6.

Table 6 Hardened properties of SCC-M50

Mix. no	P-1			P-2			P-3			P-4		
Age of curing (days)	7	28	90	7	28	90	7	28	90	7	28	90
Compressive Strength (N/mm^2)	40.25	52.44	57.24	42.25	53.7	60.75	48.26	54.5	63.27	42.4	50.64	56.25
Flexural Strength (N/mm^2)	3.45	3.78	4.62	3.94	4.5	5.42	3.97	4.8	5.9	4.32	4.98	5.1
Split tensile Strength (N/mm^2)	3.25	4.79	5.26	3.76	4.5	4.68	6.05	6.34	6.8	4.27	5.55	5.74
Shrinkage strain ($\times 10^{-6}$)	167.9	325.4	506.8	173.7	367.4	527.2	165.8	596.6	492.5	324.7	500.25	566.5

Case 4: Hardened properties of concrete at elevated temperature

In this test, the concrete specimens were heated at temperatures of 100, 150, 200 and 250 degrees Celsius for each and M50 grade optimum concrete mix specimens [40]. Moreover, by heating the samples, the exposure time of 2hrs and 4hrs, respectively. This test is performed for M40 compressive, split tensile and flexural strength, and shrinkage was evaluated for 28 and 90 days. In other existing works, the exposure time was 1hr or 2hrs; however, in this work, the exposure time was maintained for 4hrs. In this test, an axial load is applied to the concrete cube of size $15cm\times15cm\times15cm$ till the occurrence of failure. The test results of compressive strength at elevated temperatures are shown in Table 7. The SCC specimens with high temperatures normally reduce strength due to a series of physical and chemical changes.

Table 7 Obtained Compressive Strength

Compressive Strength (N/mm^2)									
Curing after	**28 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27˚C)	100˚C	150˚C	200˚C	250˚C	100˚C	150˚C	200˚C	250˚C
M-4 (M40)	48.7	47.5	46.25	45.75	43.37	46.84	44.76	42.57	40.82
P-3 (M50)	54.5	54.1	53.25	51.74	50.97	54.25	53.42	52.75	50.86
Curing after	**90 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27˚C)	100˚C	150˚C	200˚C	250˚C	100˚C	150˚C	200˚C	250˚C
M-4 (M40)	53.5	53.2	52.45	51.87	50.38	53.04	52.67	50.65	48.33
P-3 (M50)	63.27	63.04	62.72	61.63	60.69	62.90	61.86	60.64	59.41

The M50 grade concrete with P-3 mix and M40 grade with M-4 mix compressive strength was reduced due to the increase in temperature. When the temperature increases, the concrete reduces the strength from 100^{0}C in both grades with each exposure time of 2hrs and 4hrs. The optimum mix of M40 and M50 grade concrete at elevated temperatures is shown in Figure 3 and 4, respectively. The obtained compressive Strength of M-4 and P-3 mix concrete at 250^{0}C for 2hrs was 43.37 N/mm^2 and 50.97N/mm^2 at 28 days and 50.38N/mm^2 and 60.69N/mm^2 at 90 days, respectively. The M-4 mix and P-3 mix concrete were heated at 250^{0}C for 4hrs; the obtained compressive strength was 40.82N/mm^2 and 50.86N/mm^{2,} respectively, at 28 days and 48.33N/mm^2 and 59.41N/mm^2 at 90 days respectively.

The optimum M-4 and P-3 mix concrete heated at 250^{0}C for 4hrs shows lesser strength than optimum mix concrete heated at 250^{0}C for 2hrs. Compared to other works, the proposed study's compressive strengths have lesser strength reduction at elevated temperatures.

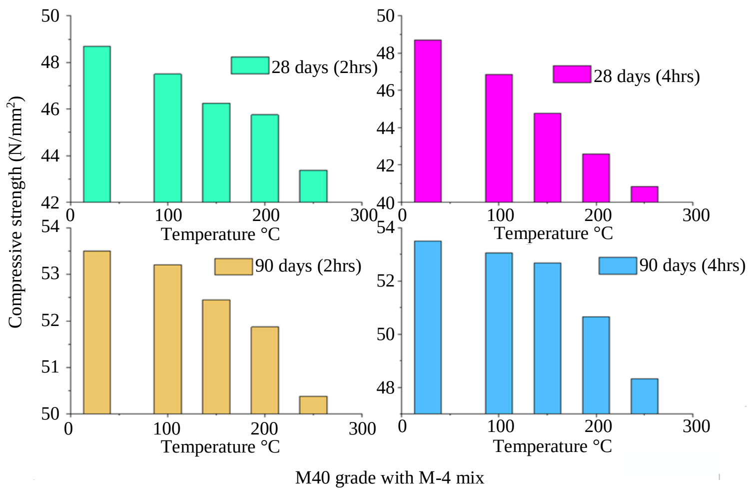

Figure 3 M-4 mix concretes compressive strength at elevated temperatures

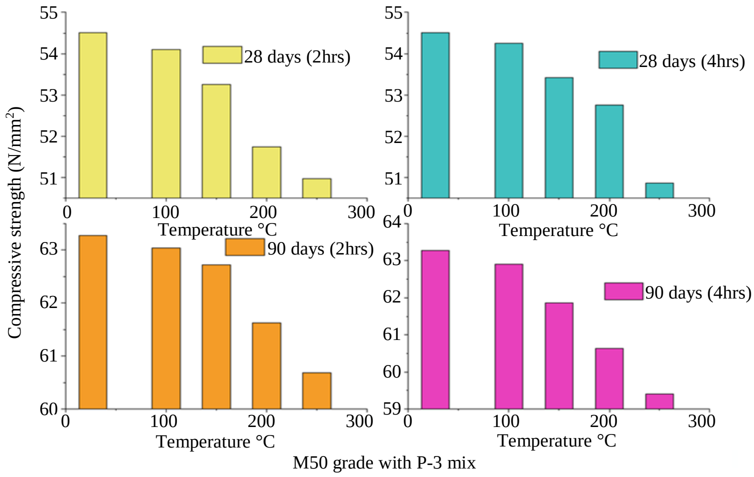

Figure 4 P-3 mix concretes compressive strength at elevated temperatures

Split tensile strength at elevated temperatures

This test determines the cracks on specimens by applying a tensile load on the cylinder. It is conducted by utilizing the concrete cylinder of size 15cm dia and 30cm height. If the concrete is brittle and weak, it develops cracks due to tensile force [42].

The SCC mixtures of M-4 mix (M40 grade) and P-3 mix (M50 grade) were heated at elevated temperatures for 2hrs and 4hrs. After heating of concrete at each temperature, the concrete split tensile strength is evaluated; the split tensile strength test result at elevated temperatures is illustrated in Table 8 and Figure 5. Also, the p-3 mix has been described in Figure 6. The M-4 mix obtained Strength of 3.7 N/mm^2 at 250^{0}C for 2hrs and 4hrs at 28days respectively, and in 90 days, the obtained split tensile strength was 6.2 N/mm^2 and 6.1 N/mm^2 at 250^{0}C for 2hrs and 4hrs respectively. The split tensile strength obtained by the P-3 mix was 5.8 N/mm^2 and 5.2 N/mm^2 at 250^{0}C for 2hrs and 4hrs at 28 days, respectively. In 90 days, the concrete split tensile strength at 250^{0}C for 2hrs and 4hrs is 6.38 N/mm^2 and 6.12 N/mm^{2,} respectively.

Table 8 Obtained Split Tensile Strength

Split Tensile Strength (N/mm^2)									
Curing after	**28 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27^{0}C)	100^{0}C	150^{0}C	200^{0}C	250^{0}C	100^{0}C	150^{0}C	200^{0}C	250^{0}C
M-4 (M40)	4.2	4.12	4.097	3.89	3.7	4.05	3.92	3.85	3.7
P-3 (M50)	6.34	6.2	6.11	5.9	5.8	6.25	6.09	5.94	5.2
Curing after	**90 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27^{0}C)	100^{0}C	150^{0}C	200^{0}C	250^{0}C	100^{0}C	150^{0}C	200^{0}C	250^{0}C
M-4 (M40)	6.9	6.8	6.73	6.4	6.2	6.7	6.64	6.4	6.1
P-3 (M50)	6.8	6.7	6.69	6.51	6.38	6.62	6.54	6.37	6.12

In tensile strength, the strengths were reduced by increasing the temperature in both optimum mixes of M40 and M50 grade after 2hrs and 4hrs exposure. The split tensile strength of concrete at 250^{0}C for 4hrs has less strength in both optimum combinations of concrete. Thus, the concrete strength was reduced by increasing temperatures at different exposure times. The presented method has lesser strength reduction at elevated temperatures than other approaches.

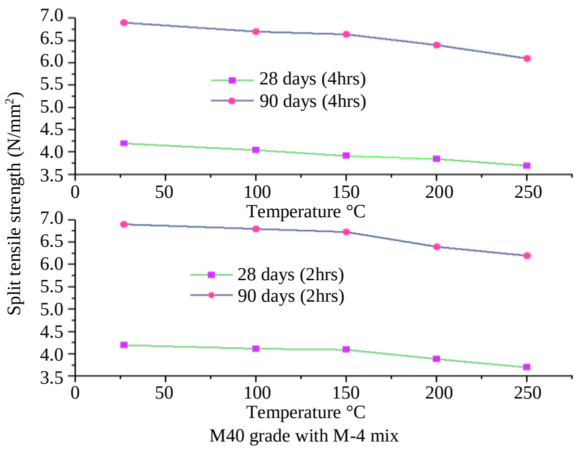

Figure 5 M-4 mix concrete split tensile strength at elevated temperature

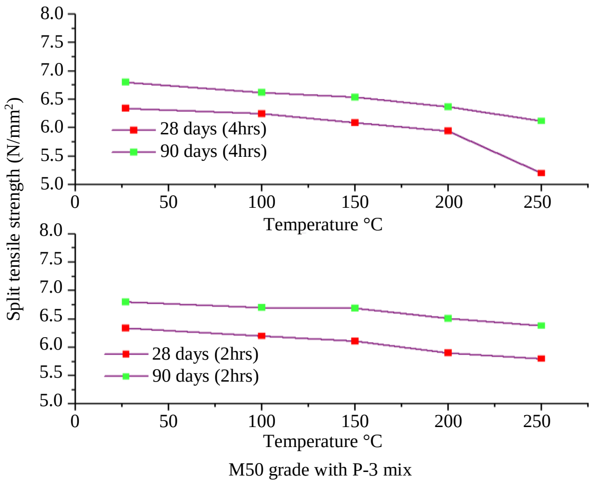

Figure 6 P-3 mix concrete split tensile strength at elevated temperatures

Flexural strength at elevated temperatures

The specimen used for testing concrete flexural strength was a beam of size 10*cm*×10*cm*×50*cm* [43]. Moreover, by increasing the curing days, flexural strength also increases. The M40 grade concrete with M-4 mix and the M50 grade concrete with P-3 mix is the optimum mix replacements for SCC.

The test result of flexural strength at elevated temperature is exposed in Figure 6 and Figure 7. The flexural Strength of M-4 mix concrete attained after heating at 250^{0}C for 2hrs was 7.82N/mm^2 and 9.41 N/mm^{2}and 7.43 N/mm^2 and 9.11 N/mm^2 for 4hrs at 28 and 90 days respectively. In the P-3 mix, the obtained flexural strength of concrete at 250^{0}C for 2hrs was 4.42 N/mm^2 and 5.59 N/mm^2 at 28 and 90 days, respectively. The flexural strength of concrete heated at 250^{0}C for 4hrs was 4.26 N/mm^2 and 5.27 N/mm^2 at 28 and 90 days, respectively.

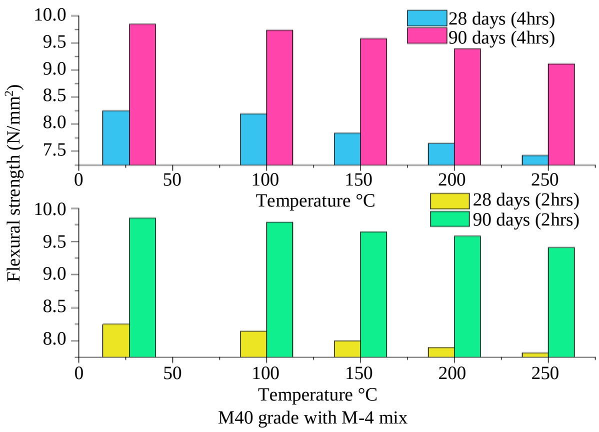

Figure 7 M-4 mix concrete flexural strength at elevated temperature

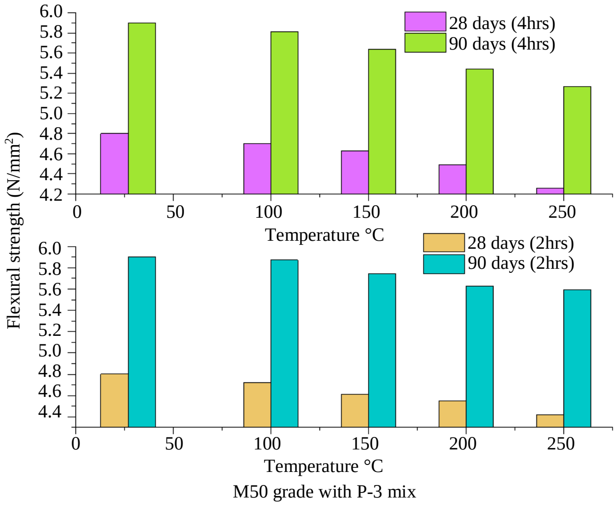

Figure 8 P-3 mix concrete flexural strength at elevated temperature

The flexural strength at elevated temperatures shows a reduction in strength due to increasing temperatures in both optimum mixes of M40 and M50 grade for an exposure of 2 and 4 hrs. The M-4 and P-3 mix flexural strength results at elevated temperatures are shown in Figure 7 and 8, respectively. Compared to other investigations, the presented method has less reduction in flexural strength at high temperatures.

Shrinkage

The shrinkage test is carried out to evaluate the SSC durability [41], and it measures length change; it allows concrete expansion or concrete volumetric contraction in the hardened state. It is a vital requirement in the practical application of concrete, and the dial gauge used in measuring the shrinkage is the least count of 0.01 mm. The test result of shrinkage strain at elevated temperatures is tabulated in Table 9.

Table 9 Obtained Shrinkage strain

Shrinkage strain ($\times 10^{-6}$)									
Curing after	**28 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27^0C)	100^0C	150^0C	200^0C	250^0C	100^0C	150^0C	200^0C	250^0C
M-4 (M40)	325.9	335.62	340.6	358.4	360.82	337.45	351.2	376.265	399.48
P-3 (M50)	596.6	597.8	598.5	599.7	601.4	598.7	600.24	604.83	609.45
P-3 (M50) optimized	141.29	139.4	137.2	135.0	132.8	137.42	134.89	127.08	119.16
Curing after	**90 days**								
Exposure time		**2hrs**				**4hrs**			
Heated Temperature	Room (27^0C)	100^0C	150^0C	200^0C	250^0C	100^0C	150^0C	200^0C	250^0C
M-4 (M40)	486.5	487.62	489.54	491.25	493.67	488.354	490	500.25	502.86
P-3 (M50)	492.5	493.4	494.92	496.67	498.5	496.25	500.84	501.54	503.52
P-3 (M50) optimized	136.58	133.72	128.88	123.38	117.66	124.7	110.4	107.98	101.82

Due to the increase in temperature, the shrinkage of concrete was increased. Developed ABbSD optimized the increased shrinkages on concrete at elevated temperatures. The optimized shrinkage strain for 2hrs and 4hrs at 250^0C in the P-3 mix was 132.8×10^{-6} and 119.16×10^{-6}, respectively.

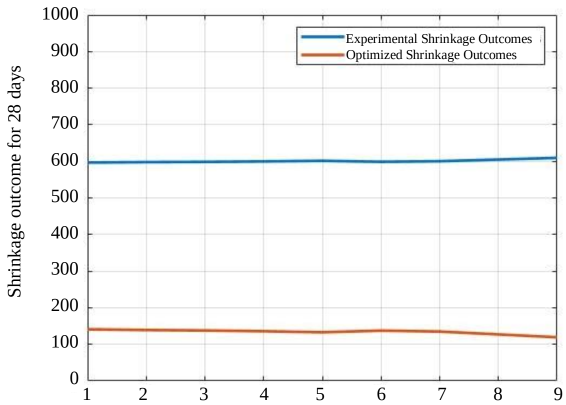

Figure 9 Before and after optimized shrinkage for P-3 mix at 28 days

The P-3 mix optimized shrinkage strain at 250^0C was 117.66×10^{-6} and 101.82×10^{-6}, respectively, for 2hrs and 4hrs at 90 days. The result of M50 grade P-3 mix before and after optimization for 28 and 90 days is shown in Figure 9 and 10, respectively.

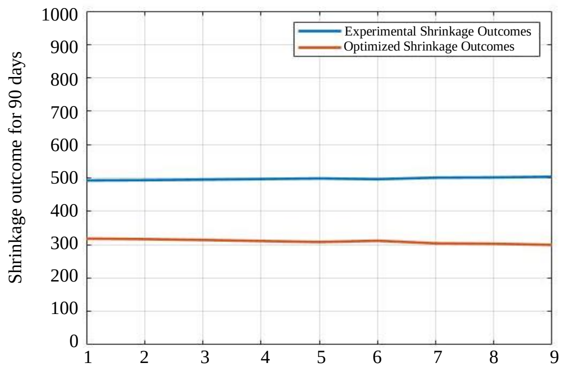

Figure 10 Before and after optimized shrinkage for M-4 mix at 90 days

Figure 11 Laboratory photos a) compression testing machine, b) Length Comparator for shrinkage calculation, c)slump flow test, d)J-ring test, e) Specimens in the oven, f) jaw crusher and broken tiles

The equipment used for this experimental process is defined in Figure 11. A specific process was executed using these tools.

5.2 Performance assessment

To determine the effectiveness of the developed SCC-M40 grade's M-4 mix and SCC-M50 grade's P-3 mix, concretes compressive, split tensile and flexural strengths at elevated temperatures were compared with existing works such as SCC [33], SCC with sugarcane Bagasse ash (SCBA) and metakaolin [36], SCC with fly ash and steel fiber [37], SCC with polyethylene terephthalate (PET) [38]. The strengths comparison at 200^{0}C is shown in Table 10.

The comparison results indicated that the presented model has higher strength than other works.

The comparison result shows the developed method has a higher compressive strength of 51.87N/mm^2 for M-4 mix and 61.63N/mm^2 for P-3 mix. The other existing mixes have fewer strengths at 2000C than M-4 and P-3. The SCC has attained a compressive strength of 38.43 N/mm^2, SCC with SCBA & metakaolin has attained a compressive strength of 50.32 N/mm^2, SCC with fly ash and steel fiber has obtained the compressive strength as 45 N/mm^2, and SCC with PET has obtained 43.6 N/mm^2. In addition, the SCC with fly ash and steel fibre has attained the tensile Strength of N/mm^2, SCC with PET has obtained 4.01 N/mm^2 tensile strength, presented M-4, and P-3 mix has attained the split tensile Strength of 6.4 N/mm^2, and 6.51 N/mm^2, respectively. Moreover, the flexural strength attained by SCC with PET was 5.6 N/mm^2; the presented M-4 and P-3 mix attained the split tensile Strength of 9.58 N/mm^2, and 5.63 N/mm^2, respectively.

To measure the reliability of the proposed design, error rate is measured. Hence, the presented P-3 mix reported 4% error rate and presented M-4 mix recorded 6% error rate, which is less compared to other mixes. Hence, the presented mixe were helped to reduce shrinkage rate in SCC, statistics are defined in Table 10. Besides, to justify the effectiveness of the proposed mixes, the past studies mixes were implemented in the same proposed platform and the performance metrics were noted.

Table 10 Comparison of strengths

Methods	Compressive Strength (N/mm^2)	Split tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Shrinkage reduction (%)	Error rate (%)
SCC [27]	38.43	3	3.8	15	34
SCC with SCBA & metakaolin [28]	50.32	3.6	4	28	16
SCC with fly ash and steel fiber [29]	45	4.2	4.2	23	21
SCC with PET [30]	43.6	4.01	5	32	18
Presented M-4 mix	51.87	6.4	9.58	40	6
Presented P-3 mix	61.63	6.51	5.63	38	4

5.3 Discussion

From the overall result, the strengths of M-4 mix and P-3 mix concrete at elevated temperatures decreased due to increased temperature. Moreover, the concrete, with the addition of broken tiles and fly ash as partial replacement in concrete, increases the strength. However, due to increased temperature, shrinkage was developed on the concrete. In addition, the shrinkage strain on concrete was optimized by the developed ABbSD; compared to other existing works, the presented work has higher strengths at elevated temperatures. Moreover, optimizing the shrinkage using the developed method attains 119.16×10^{-6} and 101.82×10^{-6} strain at 28 and 90 days for 4hrs at 250^0C, respectively. The compressive strength of concrete for M-4 mix at 250^0C for 4hrs at 28 and 90 days was $40.82N/mm^2$ and $48.33N/mm^{2,}$ respectively, and for P-3 mix, the attained compressive strength was $50.86N/mm^2$ and $59.41N/mm^2$ respectively. Moreover, concrete with higher compressive strength at elevated temperatures is suitable for all constructions. The suitable practical application for this present study is strengthening the building structure by reducing the crack rate. Besides, Graphene is the nanomaterial utilized to improve the Strength of the SCC. Hence, it is added in the percentage of 0, 0.002 to 0.1%, which reflects high performance.

After applying the graphene Nano substances, the mechanical properties were improved. The performance test against Graphene is detailed in Table 11. Hence, Graphene is suitable for the SCC.

Table 11 Performance test against Graphene

Performance testing with and without Graphene				
Methods	Compressive Strength (N/mm^2)	Split tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Shrinkage reduction (%)
Presented M-4 mix (without Graphene)	51.87	6.4	9.58	40
Presented M-4 mix (with Graphene 0.02%)	53.7	7.8	10.2	48
Presented P-3 mix (without Graphene)	61.63	6.51	7.3	38
Presented P-3 mix (with Graphene 0.02%)	62.63	8.2	5.63	45

6. Conclusion

In the present research, M40 and M50 grade concrete was prepared using 0-40% and 0-30% of fly ash and broken tiles as partial replacements of cement and coarse aggregate, respectively. Different mixes determined the optimum mix of concrete as M-4 and P-3 mix. Then the optimum mix concrete heated at elevated temperatures of 100-250^0C maintained the exposure time of 2hrs and 4hrs, respectively.

The recorded optimal compressive strength for the proposed M-4 mix is 51.87 $N/mm^{2,}$ and the compressive strength of the P-3 mix is 61.63 N/mm^2. Compared to the conventional studies, the compressive strength was improved by 10%. The split tensile of the presented M-4 mix is 6.4 $N/mm^{2,}$ and the P-3 mix is 6.51 N/mm^2; from the past study mixes, the split tensile was maximized by 2%. In addition, the flexural strength is maximized by 4%and the shrinkage was reduced by 10% than the previous studies. This outstanding performance of the designed novel ABbSD is the key advantage of this research. These finest performances were significant in avoiding building and structural movement cracks. However, the concrete strength prediction model is not implemented in this study. In future, incorporating the neural network along with this proposed solution will give better strength prediction results in civil structures. In addition, Graphene is a suitable nanomaterial to apply in SCC to increase mechanical strength.

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