

# INFLUENCE OF TEMPERATURE EFFECTS ON NANO-SILICA BLENDED SELF-COMPACTING GLASS MORTAR

## VPLIV TEMPERATURE NA SAMOZGOŠČEVALNO MALTO Z DODATKOM NANO DELCEV SILIKE

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Self-compacting mortars are achieving a great deal in the construction industry due to their remarkable characteristics and due to their advantages over conventional concrete. The main drawback associated with self-compacting mortars is the high cost associated with the ingredients used in the production of self-compacting mortars. This research aims to overcome this by combining the effects of nano-silica and glass powder on the properties of self-compacting mortar at normal and higher temperatures. The experiments were conducted to determine the split tensile strength over a range of curing periods and after being subjected to various temperatures. Durability properties of the self-compacting glass mortar, such as sorptivity, were also studied and compared with the properties of the control mortar. In addition, the chloride penetration resistance of the self-compacting mortars were also studied. The microstructure properties, such as X-ray diffraction and FTIR studies, were also performed to analyze the characteristics of self-compacting glass mortars at the micro level. The proposed mortar design can solve the problem of the disposal of waste glass, prevent the depletion of natural river aggregates and also prove to be cost effective for massive construction purposes.

Keywords: self-compacting mortar, waste glass powder, elevated temperatures

Samozgoščevalne malte postajajo, zaradi svojih dobrih lastnosti in prednosti v primerjavi s konvencionalnimi maltami na osnovi cementa, vse pomembnejše v gradbeništvu. Novinci v gradbeni industriji izražajo veliko zanimanje za pričujoče in nove trende. Glavna pomanjkljivost samozgoščevalnih malt so veliki stroški njenih izdelav zaradi dragih surovin. V pričujočem članku avtorji opisujejo raziskavo, ki bi zmanjšala stroške surovin s kombiniranjem dodatka nano delcev silike in steklenega prahu ter njenega vpliva na lastnosti malte pri sobni in povišanih temperaturah. S preizkusi so določili cepilno in natezno trdnost izdelane malte v območju temperatur njene toplotne obdelave in po njeni izpostavitvi različnim temperaturah. Določili so tudi trajnost (absorpcijo) izdelane samozgoščevalne steklene malte, ki so jo primerjali s kontrolno malto. Ugotavljali so še njeno odpornost proti penetraciji kloridov. Mikrostrukturo malte so na mikro nivoju analizirali z rentgensko difrakcijsko spektroskopijo (XRDS) in Fourierjevo transformirano infrardečo spektroskopijo (FTIR). Predlagana sestava in način izdelave rešuje problem prekomerne količine odpadnega stekla, prekomerne izrabe rečnega agregata (kamenje, pesek, mivka) in zmanjšuje stroške masivne uporabe te vrste malt v gradbeništvu.

Ključne besede: samozgoščevalna malta, prah steklenih odpadkov, povišane temperature

## 1 INTRODUCTION

Self-compacting mortars have achieved considerable development and are now a leading instrument in concrete technology for the past two decades.<sup>1</sup> Generally, self-compacting concretes contain fewer coarse aggregates than the other conventional concrete types which mark the importance of mortar properties in self-compacting concretes.<sup>2</sup> The fine aggregate was substituted by plastic waste at various dosages and the fresh and hardened characteristics of the mortar were analyzed. An innovative new mixture design for the self-compacting glass mortar was performed.<sup>3</sup> Moreover, ample opportunities to use waste materials as aggregates and cement replacements are available while designing a self-compacting concrete mix through the increment of fines con-

tent.<sup>4</sup> The use of natural resources for the development of infrastructure has posed a danger to environmental sustainability. Glass powder as cement replacements can react with calcium hydroxide in cement to form hydration products that possess cementitious properties.<sup>5</sup> The resulting effect is the alkali-silica reaction (ASR), leading to the expansion of the concrete system. However, the ASR expansion effect can be reduced by the addition of pozzolanic materials with a high CaO content, which helps in the non-reduction of the pH of concrete. The glass powder additions in concrete can serve the purpose of both the filler and as pozzolanic admixture.<sup>6</sup> Moreover, the pozzolanic effect of glass powder enhanced the content of CSH that reduced the creep of the concrete. Hyeong Lee et al. found that the waste glass sludge incorporated in concrete exhibited an improved mechanical performance in later ages due to the inherent amorphous nature of the waste glass sludge.<sup>7</sup> Nanotech-

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nology is one of the pioneer industries that are now actively involved in the production of materials that can be used to serve several purposes in construction industry.<sup>8</sup> The high costs associated with the production of nanomaterials on a large scale and to limit the average particle size of the nanomaterials are some of the practical complications that limit the research into the field of nanotechnology.<sup>9</sup> The physical property of the nanomaterials, such as high specific area, improves the reaction sites in the concrete by forming additional hydration products.<sup>10</sup> The inclusion of nanomaterials can reduce the porosity of concrete, which is a crucial parameter that affects the strength of concrete by keeping the moisture intact and thus maintaining the concrete structure and integrity after exposure to high temperatures.<sup>11</sup> To assess the effect of nano and micro silica on the properties of Portland cement mortars with various dosages of superplasticizers. The rheological properties showed decreased flow time with the mineral admixture addition. The study concluded that the addition of micro and nano silica could improve the compressive strength of the cement system when used in combination with an appropriate superplasticizer. A critical review of the ultra-high-performance concrete containing nanomaterials which stated that the addition of nano silica particles causes a reduction in porosity and capillary pores in the concrete through refining the pore structure.<sup>12</sup> The nucleation of CSH gel occurs on the silica surface due to the addition of nano silica content. However, the dispersion of nano silica in the concrete must be taken care when adopting higher percentage additions. Concrete after exposure to fire can undergo several degrees of damage and hence precise information on the behaviour of concrete structures during and after exposure to fire is necessary.<sup>13</sup> Though concrete is a poor conductor of heat, severe damage may occur when a maximum temperature of 1000–1300 °C is reached during a fire.<sup>14</sup> Temperature studies on concrete are essential to determine whether the concrete has been completely burnt or is structurally sound. Self-compacting concrete usage has increased multifold in the past few decades due to its higher strength variations than conventional concrete.<sup>15</sup> The effect of the cooling method adopted also played a significant role on the strength reduction. The shape of the specimen and the temperature profile inside the specimens were also considered as an influential parameter on the strength variation. The main objective of this research work is to develop a glass mortar that is self-compacting in nature and to conduct a systematic investigation of the strength and durability of the developed self-compacting glass concrete. The present study contributes towards a clear understanding of the possibility of using waste glass powder as an effective fine aggregate replacement in nano-silica modified, self-compacting mortar. Self-compacting mortars are now becoming an integral construction material due to their widespread use in retrofitting and rehabilitation works. The use of al-

ternative materials as fine aggregate leads to a reduction in the quarrying of natural sand from riverbeds, thereby minimizing the environmental impacts. The study also contributes to a reduction in the accumulation of waste glass in the environment that causes disposal problems. Thus, the present work will help to produce an economic and eco-friendly self-compacting mortar with improved properties.

## 2 EXPERIMENTAL PART

### 2.1 Materials

Cement used in the present study is Ordinary Portland Cement (OPC 55) from Coramandel cement, having a specific gravity of 3.15. Nano silica is spherical in nature having the size in the range of 2–100 nm, specific gravity 1.31 and is produced synthetically either in dry form or in colloidal nature. The fine aggregate with a specific gravity of 2.66 used in the present study includes the natural river sand conforming to zone II of grading of BIS: 383 1970. The glass powder used in the present study is sieved in a 600 µm sieve to remove the coarse fractions. The density of the glass powders as measured through volumetric method was  $(1.08 \pm 0.02)$  g/cm<sup>3</sup>. The water used in the present investigation is potable without major impurities. In the present study, CONPLAST SP 430 of IS: 9103-1999, which is a naphthalene based superplasticizer, is used as a water reducing agent.

### 2.2 Methodology

Nano silica was added 3 w/% of cement in the glass powder replaced mixes. The proportion of the self-compacting mortar and mix design are shown in **Table 1** and **Table 2** respectively.

**Table 1:** Mix ID details and proportion of the mortar specimens

mix ID	binder		fine aggregate		super-plasticizer dosage (w/%)	w/b ratio
	Cement (w/%)	nano silica (w/%)	river sand (w/%)	glass powder (w/%)		
SCM	100	0	100	0	1.5	0.4
SCGM1	100	3	90	10	1.5	0.39
SCGM2	100	3	80	20	1.5	0.38
SCGM3	100	3	70	30	1.5	0.37
SCGM4	100	3	60	40	1.5	0.35
SCGM5	100	3	50	50	1.5	0.34

**Table 2:** Mortar mix proportion for normal self-compacting mortar

constituent	cement (kg/m <sup>3</sup> )	sand (kg/m <sup>3</sup> )	water (kg/m <sup>3</sup> )	super-plasticizer (kg/m <sup>3</sup> )	W/B (water/binder)
SCM	700	1372.4	276	10.6	0.4

Initially, the self-compacting glass mortar specimens were heated in the furnace from room temperature to 800 °C in increments of 200 °C. The specimens after



reaching the target temperature were in the furnace for duration of 2 h to ensure uniform heating of the specimen throughout their cross-section. The heated specimens were cooled to room temperature and then subjected to various experimental tests. The splitting tensile strength is calculated on cylindrical specimens of size 100 mm diameter and 200 mm height after 28 d curing of the specimens. The splitting tensile strength is calculated using Equation (1).

$$f_s = \frac{2P}{\pi \cdot d \cdot l} \tag{1}$$

Where,  $P$  is load at failure of the specimens,  $d$  is diameter of the specimens,  $l$  is length of the specimens. The sorptivity test was conducted as per the procedure stated in ASTM C1585 on circular discs of size 100 mm diameter and 50 mm thickness. The capillary absorption of water was calculated for various time intervals up to 7 d and the water absorption coefficient of sorptivity was determined using Equation (2).

$$S = \frac{w}{a\sqrt{t}} \tag{2}$$

Where,  $w$  is cumulative weight of water absorbed,  $a$  is cross sectional area of specimen,  $S$  indicates sorptivity coefficient,  $t$  is the time of contact of specimen with water. The RCPT test is conducted on the specimens water cured for 28 d and after exposure to various temperatures. The RCPT test is conducted on the specimens that were water cured for 28 d and after exposure to various temperatures. The specimen size used for the RCPT test is cylindrical specimen of size 100 mm × 50 mm and the amount of electric current passed through the specimen is measured. The total charge passed through the cylindrical specimen measures the electrical conductance which is calculated the Equation (3).

$$Q = 900 (I_0 + 2 I_{30} + 2 I_{60} + 2 I_{90} + 2 I_{300} + 2 I_{330} + 2 I_{360}) \tag{3}$$

Where,  $Q$  is charge passed in coulombs,  $I_0$  is current immediately after voltage is applied in amperes,  $I_t$  is current at  $t$  minutes after voltage is applied in amperes.

Mercury intrusion porosimetry (MIP) is one of the most widely used techniques for characterizing the pore structure of cementitious materials. From MIP the pore size and pore volume can be obtained, from which the information and percentage porosity and pore diameter can be inferred. In addition, the surface area of particle and the median pore diameter can also be obtained. The specimens used for the cubic specimens after 28 d curing and after being subjected to a temperature of 800 °C. Before this analysis is carried out the specimens were pre-conditioned by immersing in ethyl alcohol and dried in an oven at (50 ± 5) °C. The XRD patterns were obtained from the powdered mortar mixes before and after subjected to high temperatures were studied in 600-µm sieve. The crystalline phases present in the mortar were identified through the patterns obtained from X-ray

diffractometer (Xpert Pro, PANalytical) that uses Cu- $K_{\alpha}$  radiation with  $\lambda = 0.154$  nm and the patterns were recorded at a 2° theta angle ( $2\theta$ ) ranging from 10° to 80°. The FTIR spectral curves of the self-compacting glass mortar before and after exposure to temperatures were obtained using Shimadzu IR Tracer equipment. The spectra were recorded on the powdered samples mixed with 99 % KBr mixture and the patterns were recorded at transmission modes at a wavelength ranging from 400–4500  $\text{cm}^{-1}$ .

### 3 RESULT AND DISCUSSION

Earlier the fresh state properties by mini funnel and mini slump test are presented and read to know the basic factors on utilizing these materials.<sup>16</sup> It revealed that these do not cause any detrimental effects in the fresh state resulting in achievable practical applications. It is here extended for the investigation and discussed below.

#### 3.1 Split tensile strength

The splitting tensile strength of the self-compacting mortar containing various percentages of glass powder as a partial replacement for fine aggregate is shown in **Figure 1**. The split tensile strength of the self-compacting mortar mixes were shown in comparison to the reference mix. The variation in the strength clearly justified the contribution of the nano silica and glass powder to the improvement of the split tensile strength. The splitting tensile strength was found to decrease with increasing glass powder content due to the brittleness contributed by the glass powder. Nano silica though improved the strength of the mortar, and the final result was a decrease in the split tensile strength. The splitting tensile strength of the glass mortar containing 50 % glass powder was lower than the control mortar. The strength reduction at 28 d was about 27 % when compared to a normal mortar

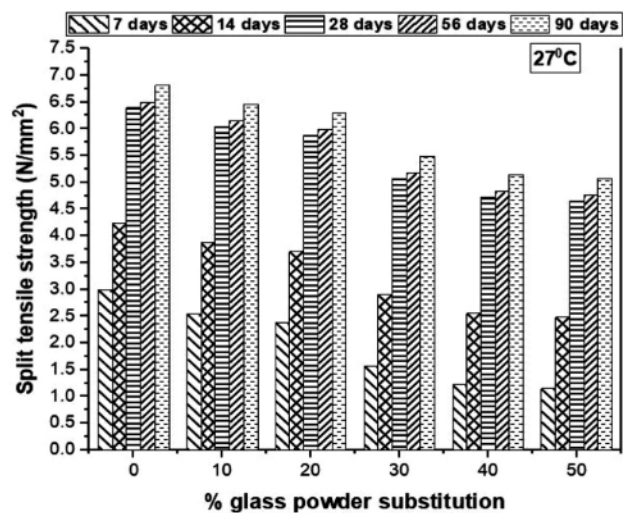


Figure 1: Split tensile strength values of various SCGM mixes

mix for the SCGM5 mix that contained 50 % glass powder substitution. The linear decrement in the splitting tensile strength of the mortar was observed at all ages. The high brittleness of the glass powder caused a reduction in the splitting tensile strength of the mortar. The increasing ages of the self-compacting glass mortar showed relatively lesser magnitude of loss due to the pozzolanic action of glass powder and nano silica. However, the values presented were acceptable and the decrease was only marginal due to the active reaction of nano silica in the mortar that resulted in the formation of reaction products with higher strength than the normal self-compacting mortar.

The splitting tensile strength of the mortar at various ages and after exposure to various temperatures is shown in Figure 2. The reduced splitting tensile strength may be due to the temperature increase, which caused a loss in the moisture of the mortar, thereby increasing the pores in the mortar. The splitting tensile strength is related to the tensile property of the mortar and hence the substitution of brittle material in the mortar has caused a reduction in this splitting tensile strength. However, the reduction in the splitting tensile strength at higher tem-

peratures occurred at a lower magnitude when compared to the normal mortar mix, which may be due to the transition of the glass powders at high temperatures that partially contributed to the minimal reduction in the splitting tensile strength. In contrast to the compressive strength results, nano silica played no role in increasing the splitting tensile strength of the mortar at all temperatures.

### 3.2 Sorptivity

The sorptivity values were reduced due to the substitution of glass powder in the self-compacting mortar, as shown in Figure 4a. The reduction in the water binder ratio required to produce the self-compacting nature of the mortar caused by the glass powder substitution minimized the amount of free water available in the mortar. This reduction in the free water minimizes the voids caused due to the loss of evaporable water, thereby minimizing the water channels in the mortar. The reduction in the sorptivity values may also be due to the plugging of the pores in the mortar by nano silica and improved solid volume formed by the additional CSH gel that forms

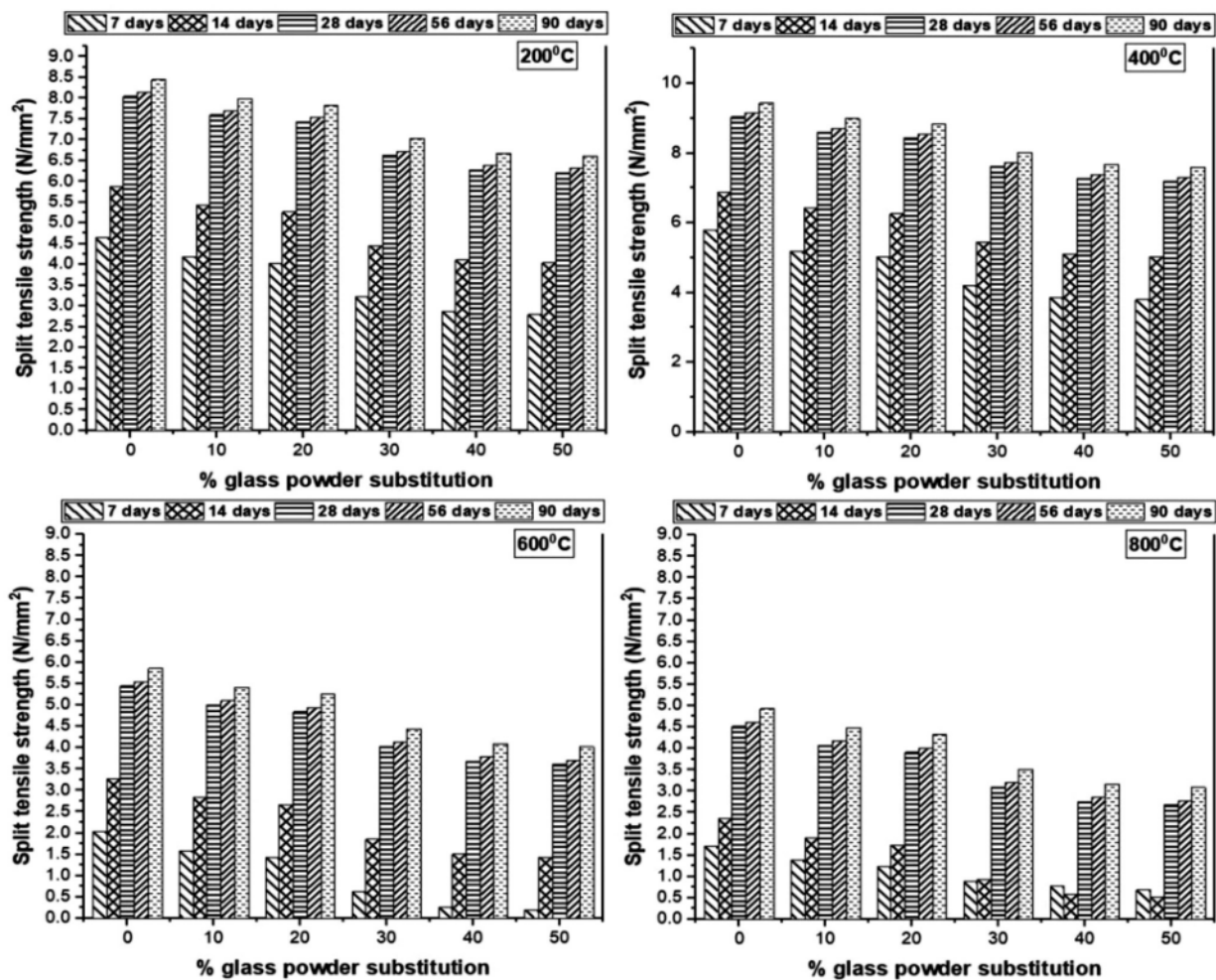


Figure 2: Residual split tensile strength of SCGM at elevated temperature



thick layers in the mortar leading to a reduction in the capillary pores. The nano silica also has the potential for converting the  $\text{Ca}(\text{OH})_2$  into calcium silicates through pozzolanic action. These additional silicates occupy the interfacial transition zones between the aggregates and cement paste, thereby blocking the pores that act as continuous water transport channel. The transition zone is the weaker region due to the less dense nature that creates a pathway for the ingress of water by acting as capillary channels, which is the reason for the increasing capillary pores in the mortar. This clearly shows the positive influence of nano silica and glass powder replacement in reducing the volume of permeable pores and thereby reducing the amount of water uptake by the surface of the self-compacting mortar. The reaction of nano silica with the cement paste forms additional CSH gel, which is highly stable, thereby reducing the capillary water absorption of the mortar at increasing temperatures. The micro and macro pores present in the mortar are filled by the finer glass powder particles, thereby improving the permeability properties of the mortar at all temperatures.

### 3.3 Rapid chloride permeability test

The rapid chloride permeability test for the self-compacting mortar mixes at normal and after being subjected to elevated temperatures is shown in Figure 4b. The total charge passed through the glass-powder-substituted mortar mixes reduced significantly with an increase in the glass-powder content. The values were quite less than the control self-compacting mortar (SCM) and the value

was found to be lesser for SCGM5 when compared to the self-compacting mortar due to the blocking effect caused by glass powder. The hydration of ions through the mortar is electrolytic through the cement paste and the aggregates do not contribute to the passage of ions due to their high electrical resistivity. The conductivity of the ions through the pore solution in the mortar plays a significant role in the ion-migration process. The type of ions dissolved in the pore solution modifies the penetration of ions through the mortar. The electrolytic ions such as  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{OH}^-$  and  $\text{Ca}^{2+}$  take part actively in the penetration of ions. The presence of positively charged ions arising from the metal ions induces the penetration of ions improving the ionic migration process. The presence of  $\text{OH}^-$  ions in the pore solution causes a significant amount of transport of ions during RCPT because the  $\text{OH}^-$  ions function as a supporting electrolyte for the chloride ions. The negatively charged chloride ions move towards the pores present in the mortar until the resistance is offered by the pore contribution. The type of mineral admixture added determines the amount of  $\text{OH}^-$  ions present in the pore solution. The  $\text{OH}^-$  ions generally deplete due to the pozzolanic action through a decrement in the  $\text{OH}^-$  ions present in the pore solution. When the density of mortar is increased the porosity is reduced, thereby improving the resistivity against the ionic migration, which directly reduces the passage of charge through the mortar. The addition of nano silica to the mortar causes a decrease in the chloride penetration of the self-compacting mortars with a higher percentage of glass powder replacement for fine aggregate. The inclu-

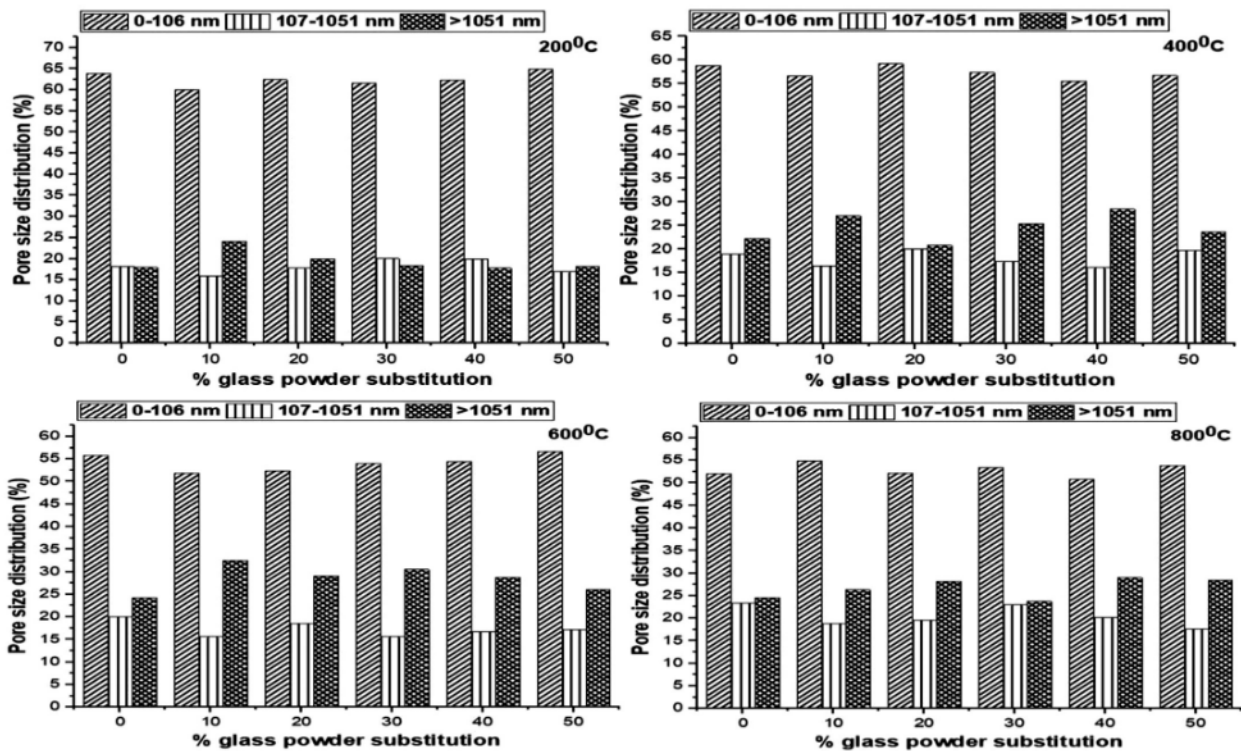


Figure 3: Pore size distribution of various SCGM mixes at elevated temperatures

sion of nano silica in the mortar caused a decrease in the amount of excessive free water content in the self-compacting mortar mixes. The presence of less free water can reduce the separation of the materials present in the mortar. Generally, the greater interfacial area between the glass powder and the cement paste creates micro voids and pores that allow the travel of the chloride ions through the pores in the mortar. This decrease in the porosity may be due to the low water-binder ratio adopted in the self-compacting glass mortar mixes that reduced the formation voids, thereby decreasing, which leads to an increase in the resistance to chloride penetration of the mortar. Moreover, the lack of free water also minimizes the formation of micro channels that forms porous path through which the chloride ions can penetrate.

### 3.4 Mercury intrusion porosimetry

The porosity and the pore size distribution of the mortar specimens are obtained using the mercury intrusion porosimetry technique. The MIP technique has been conducted on self-compacting mortars with and without the presence of nano silica and glass powder. The graphical representation of the percentage porosity of the mortar specimen after subjecting it to 28 d curing is shown in Figure 4c. From the figure it can be inferred that the control specimen self-compacting mortar exhibited the highest porosity percentage followed by the other mixes in the order of increasing glass-powder substitution. The

low porosity may be contributed by the nano silica that acted as nucleation sites for the hydration process to take place. In addition, nano silica themselves participated in the hydration process, leading to the formation of a secondary hydration product. The pozzolanic property of the glass powder also forms an extra CSH gel due to the combined effect of nano silica and glass powder, extra solids are added to the mortar thereby increasing the volume of the solids. This increment in the solid volume densified the microstructure of the mortar and reduced the capillary pores by filling the pore spaces. A decrement in the porosity percentage with increasing glass powder substitution shows that glass powder exhibits better performance in porosity reduction when used as a fine aggregate in combination with nano silica. The refinement of the micro pores through the nano silica addition causes continuous filling of the pores in the mortar by also acting as fillers. The finer size of the nano silica and the well graded fine aggregates improved the pore properties of the mortar through increasing the packing density. From the figure, the poorest porosity performance was observed in the control mortar with the increased cumulative pore volume when compared to the reference mortar.

The strength of the mortar mainly depends on the microstructure properties. The physical filling of the pore spaces has led to a decrease in the macro pores, thereby the maximum occurrence of the pores were in the diameter ranging from 0–106 nm, which are regarded

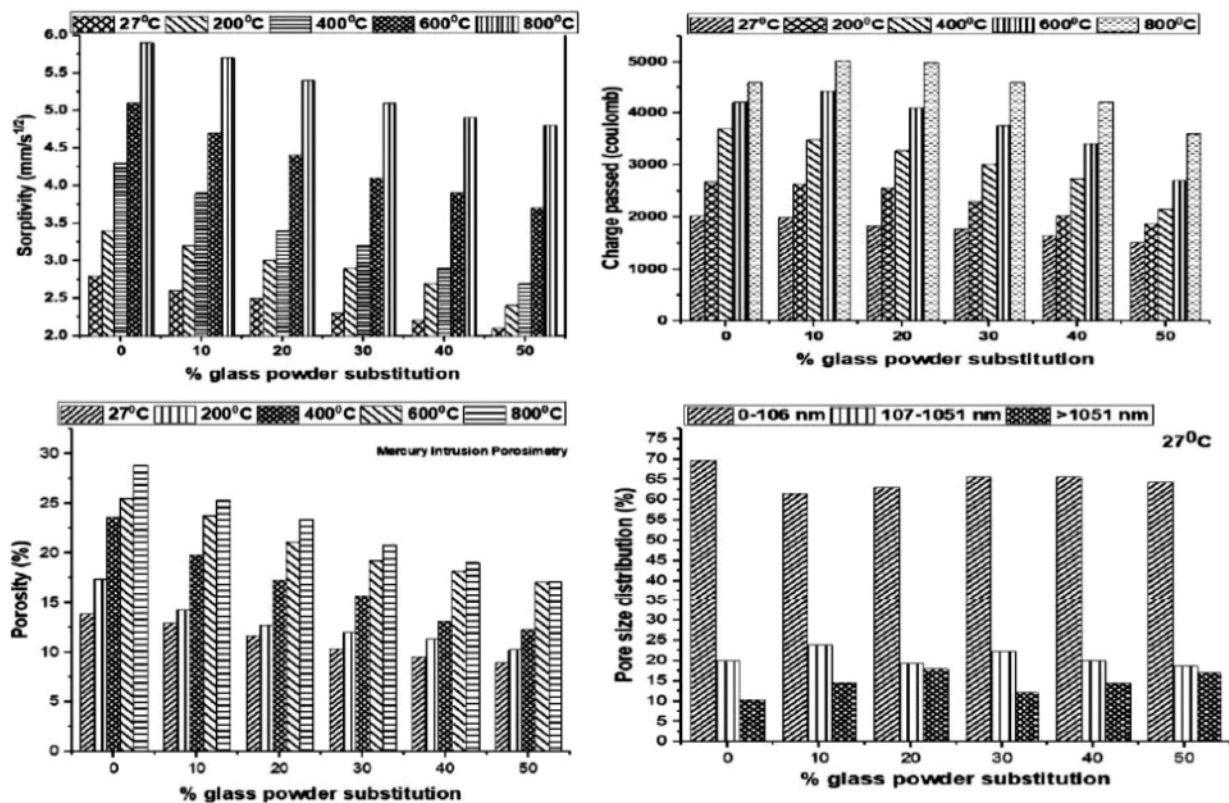


Figure 4: Results for various SCGM mixes: a) sorptivity, b) charge passed, c) MIP values of at elevated temperatures, d) pore size distribution



as micro pores. The macro pores within the size ranging from 107 nm to 1050 nm occurred in all the mixes, but at varying degrees. The control mortar (SCM) showed the highest value of 68 % micro pores when compared to other mixes. The presence of micro pores accounted for about 15 % of the mix SCGM5, indicating the contribution of the glass powder and the nano silica to the pore size reduction. The decrease in percentage of mega pores of pore diameter greater than 1050 nm was observed in all the glass-powder-substituted, self-compacting mortar mixes. This attributes the pore-filling characteristics of glass powder. The inclusion of nano silica also led to the densification of the pore structure of the mortar. The dual property of filling and densification exhibited by the glass powder and nano silica together has helped to refine the mega and micro pores of the self-compacting mortar. The variability in the sizes of the pores significantly affects the durability of the mortar. When the dimension of the pores is greater than 106 nm, they act as channels for the transport of water leading to the capillary action. The presence of pores with a diameter greater than 100 nm makes the self-compacting mortar highly permeable. Hence, the percentage of pores whose diameter lies between 0–106 nm should be given much care during the durability studies of mortar. The pore distribution of mixes is presented in **Figure 3** and **Figure 4d** respectively.

#### 4.5 X-ray diffraction

The XRD technique is the most used for the identification of crystalline phases present in cementitious material. The present study tries to explore the feasibility of using glass powder as a fine aggregate in nano-silica-modified, self-compacting mortar. The mineralogical characteristics of the produced mortar mixes have been studied using XRD analysis. The analysis was conducted using an Xpert 3 PANalytical model diffractometer. The XRD analysis on the 28-days water-cured self-compacting mortar mixes is shown in **Figure 5**. The graph is plotted with intensity counts as ordinates with 2-theta angles on the abscissa. The various mineralogical phases present in the mortar mixes is shown in the figure by comparing with the JCPDS XRD data file. It can be observed that portlandite, quartz, calcium silicate and calcite are the major phases present in the mortar. Some intensity peaks of ettringite are also found in the self-compacting mixes without a nano silica addition. The strength and durability of the mortar is influenced greatly by their mineralogical composition. The calcium silicate phase is present in all the mortar mixes, which chemically corresponds to the tri-calcium silicate  $C_3S$  present in the cement. The early age strength of the mortar is due to the hydration of  $C_3S$ . The calcium silicate phase is present in self-compacting glass mortar mixes, whereas only minute traces are found in the control mix. Hence, the early age strength of the glass mortar mixes may be contributed by this calcium silicate phase.

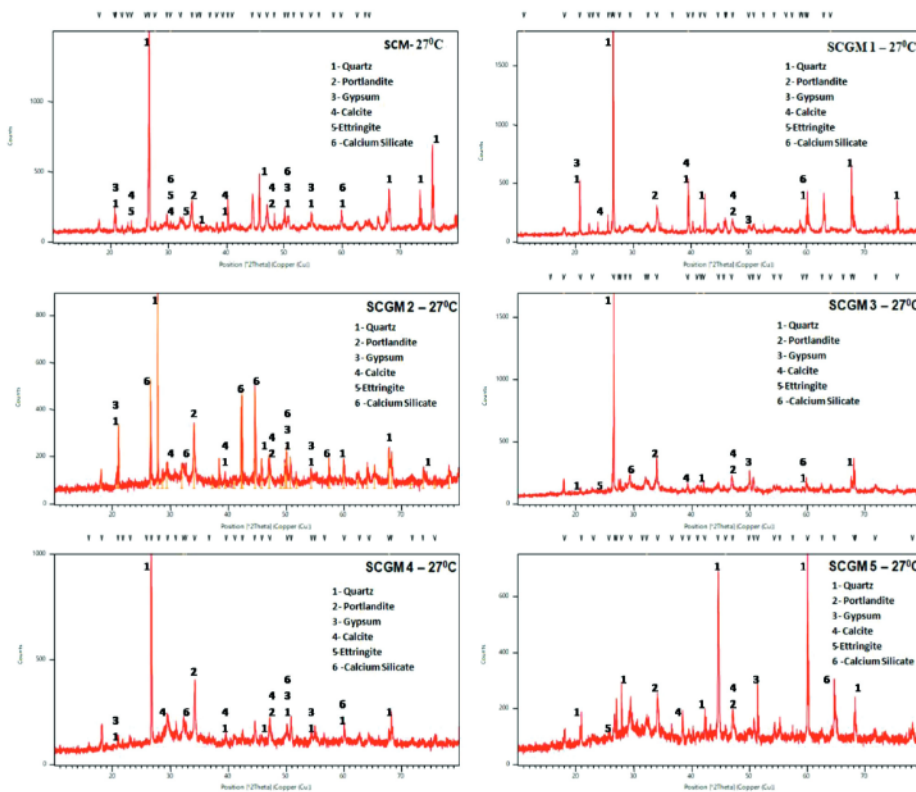


Figure 5: XRD spectral curves of control mortar (SCM) and self-compacting glass mortar mixes (SCGM) at 27 °C

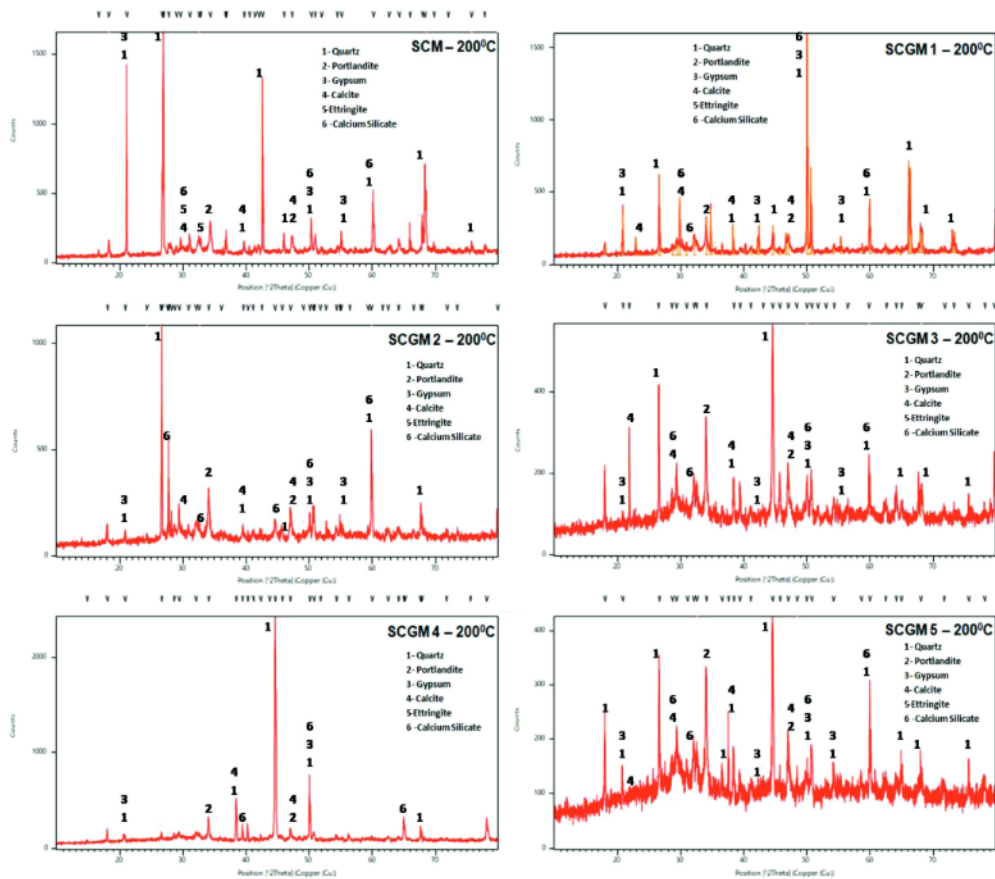


Figure 6: XRD spectral curves of control mortar (SCM) and self-compacting glass mortar mixes (SCGM) at 200 °C

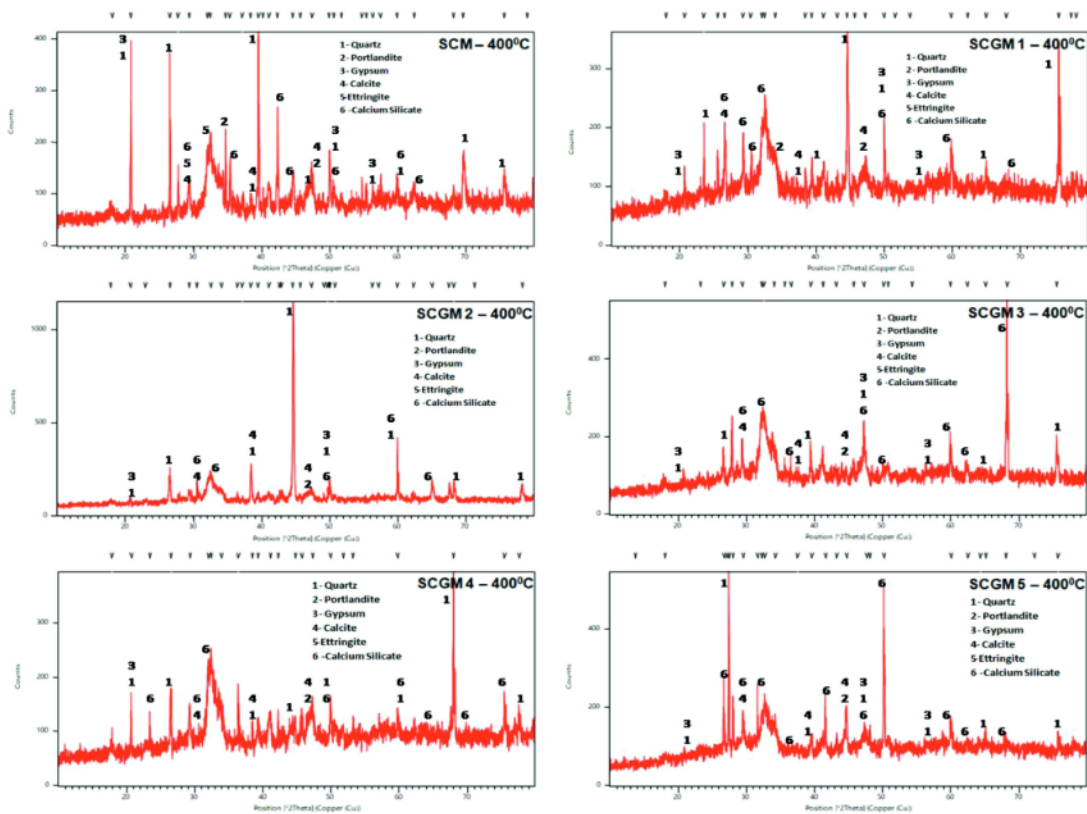


Figure 7: XRD spectral curves of control mortar (SCM) and self-compacting glass mortar mixes (SCGM) at 400 °C



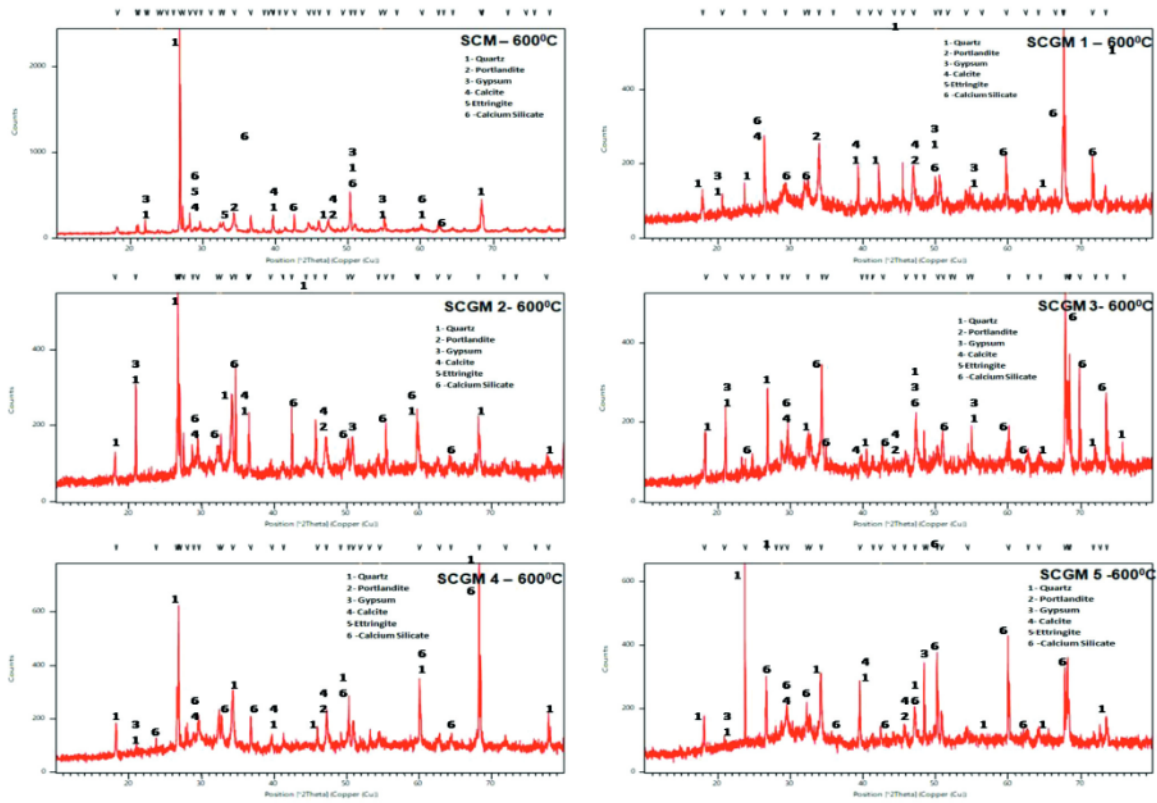


Figure 8: XRD spectral curves of control mortar (SCM) and self-compacting glass mortar mixes (SCGM) at 600 °C

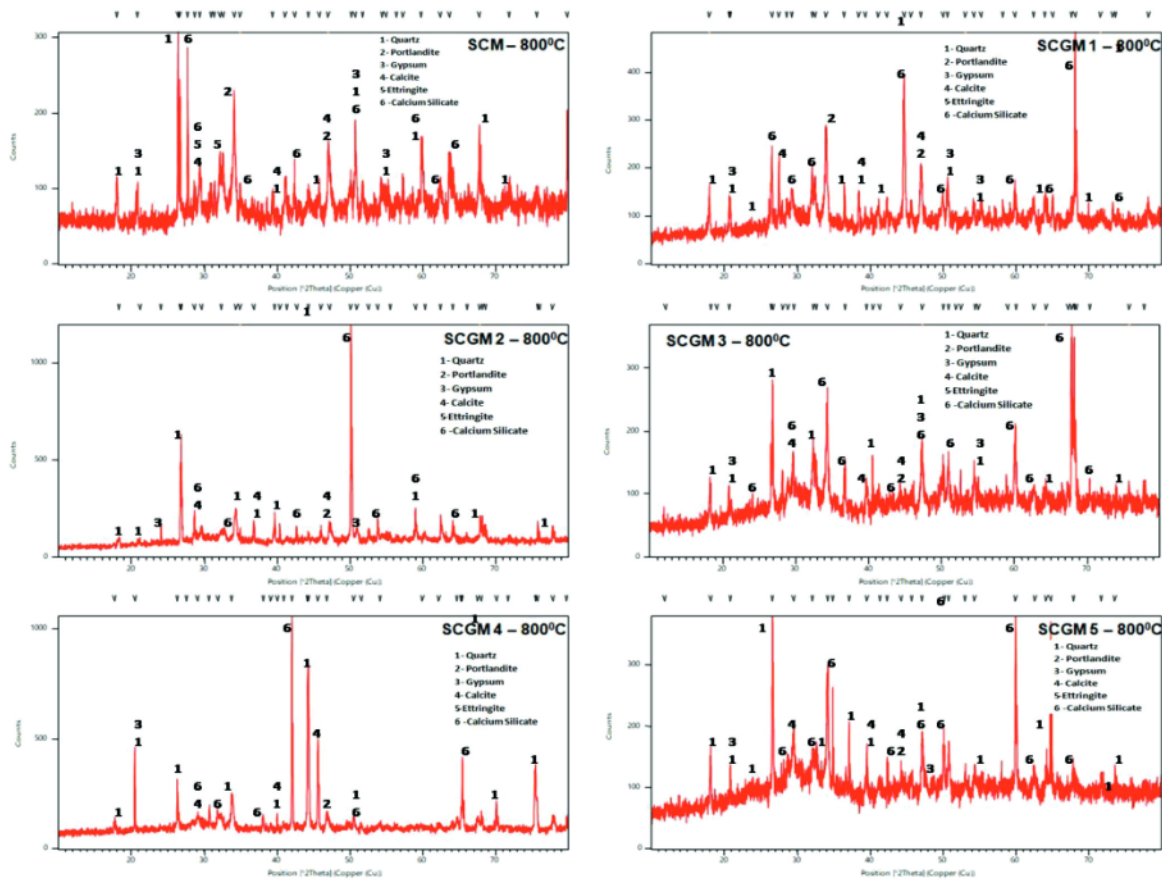


Figure 9: XRD spectral curves of control mortar (SCM) and self-compacting glass mortar mixes (SCGM) at 800 °C





glass-powder-substituted mortar mixes, which indicates the formation hydration products that are well developed. The band at around  $3500\text{ cm}^{-1}$  also indicates the presence of the  $\text{Ca}(\text{OH})_2$  hydration product. The reduced intensity of the OH band significantly indicates that the pozzolanic reaction has taken place by the transformation of the  $\text{Ca}(\text{OH})_2$  to CSH gel by the nano silica additions. The appearance of the broad band at  $3500\text{ cm}^{-1}$  also indicates the water crystal lattice present in the CSH gel. The band formed at around  $980\text{ cm}^{-1}$  belongs to the CSH gel formation. The **Figure 10a** clearly shows that the CSH gel band becomes broader and wider with higher transmission values in all the self-compacting glass mortar mixes when compared to the normal self-compacting mortar mix. This shows that the interaction between the nano silica and the glass powder has taken place, leading to more stable hydration products. Thus, it can be further confirmed that the improvement in the strength of the self-compacting glass mortar mixes was due to the formation of the CSH gel caused by nano silica additions. Quartz is identified by the transmission peak that occurs at around  $850\text{ cm}^{-1}$ . At around  $1090\text{ cm}^{-1}$  the asymmetrical stretching vibration occurs, which corresponds to the Si-O-Al stretching vibration arising from the substitution of glass powder in the mortar.

The FTIR spectral curves of the self-compacting mortar specimens after exposure to elevated temperatures are shown in **Figures 10b to 10e**. The broad -OH peak occurs around  $3400\text{ cm}^{-1}$ . This -OH peak denotes the water molecules that are physically or chemically absorbed by the constituents of the self-compacting mortar and this was found to decrease with increasing temperatures. The dehydration reaction occurring at increasing temperature was evident from the reduced -OH stretching vibration at around  $3400\text{ cm}^{-1}$ . The crystalline silica phases were evident from the band occurring at around  $1000\text{ cm}^{-1}$  and  $780\text{ cm}^{-1}$ . The band appeared less intense at around  $1423\text{ cm}^{-1}$  with increasing temperatures, which is due to the thermal dehydration of the  $\text{Ca}(\text{OH})_2$  product. The bands at around  $1000\text{ cm}^{-1}$  and  $780\text{ cm}^{-1}$  correspond the crystalline phases of quartz arising from the silica components in the self-compacting mortar. The CSH gel, which is the prominent binder of the self-compacting mortar, is identified from the corresponding peaks occurring at  $850\text{ cm}^{-1}$ . This peak was found to disintegrate due to the hybridized product formation of the self-compacting glass powder mortar mixes after exposure to temperatures. The structure of the CSH is clearly modified in all the mixes with increasing temperatures. This modification has led to the increase or decrease in the properties of the mortar, as stated through above results. The absorption band at around  $1645\text{ cm}^{-1}$  also corresponds to the chemically bound water molecules present in the calcium silicate hydrates of the self-compacting mortar, which was var-

ied for each self-compacting mortar mix, depending on the glass powder substitution and varying temperatures.

#### 4 CONCLUSIONS

Adding to the earlier investigation <sup>16</sup> it is concluded that the formation of gypsum and ettringite reduces the strength of the mortar by forming micro cracks, subsequently leading to a reduction in the strength of the mortars. The quality of the mortars as graded using chloride penetration resistance showed excellent behaviour. The chloride penetration is also well established from the results. The decrease in the inter connectivity of the pores reduced the penetration of aggressive agents into the mortar. The X-ray diffraction patterns clearly showed improved peaks of CSH and relatively less-intense CH crystals in the self-compacting glass mortar. The major peaks were almost present in the self-compacting glass mortar at elevated temperatures, indicating the thermal stability of the reaction products present in the self-compacting glass mortar due to the synergistic effect of nano silica and glass powder. The FTIR spectra also showed broad spectral OH bands indicating the formation of well-hydrated reaction products. The presence of silicate bands shows the ability of the produced mortar to sustain high temperature. Summarizing the results it can be concluded that the proposed blend of materials can be used in practical applications.

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