American Concrete Institute

UNIVERSITY OF TEXAS ARLINGTON

FIRE PERFORMANCE OF HYBRID FIBER REINFORCED SELF CONSOLIDATING CONCRETE WITH GLASS POZZOLAN

ACI Concrete Convention, 2022
Orlando, Florida

University of Texas at Arlington – Department of Civil Engineering

Rishabh Kumar, EIT
Graduate Student

Nur Yazdani, Ph.D., P.E
Professor

Eyosias Beneberu, Ph.D., P.E
Assistant Professor of Research

Outline

- Introduction
- Problem Statement
- Objectives
- SCC Mix Design
- Tests Performed
- Test Results
- Conclusions

Introduction

- Self-consolidating concrete (SCC) can easily move and fill congested areas and complex formworks.
- Hybridization refers to the reinforcement of concrete using two different types of fibers, usually macro and microfibers.
- The macro fibers provide mechanical strength and toughness, whereas the microfibers prevent concrete from spalling and crack propagation under fire.
- The macro-fibers include steel, carbon, and glass fibers, while the microfibers include polypropylene, polyethylene, and polyvinyl alcohol.

Self-consolidating concrete

Carbon Fibers

Polypropylene Fibers

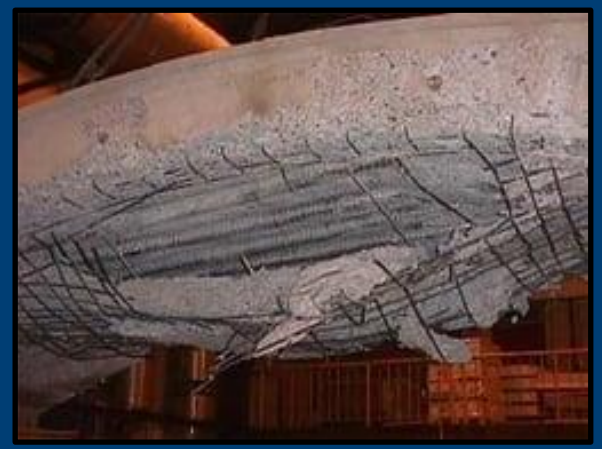
Glass Fibers

Steel Fibers

Introduction

- Excessive use of cement in construction has raised environmental concerns, while the shortage of fly ash has encouraged researchers to investigate new cement replacement methods.
- Approximately 8.4 million tons of glass are disposed in the U.S. landfills annually. Substituting glass pozzolan (GP) for cement can reduce environmental concerns while at the same time utilizing an abundant resource.
- A fire causes concrete to undergo physical and chemical changes, resulting in strength deterioration.

Glass landfill



Structural damage to concrete due to spalling

Robl, T. L., & McCormick, C. J. (2021). We Are Running Out of Fly Ash: The Nature of Regional Supply Problems.
Kaminsky et al., (2020). Ground-Glass Pozzolan for Use in Concrete. 9

Problem Statement

- Fiber reinforcement, cement replacement and strength evaluation of vibrated concrete under fire has been researched over the years. However, there is limited investigation on the fire performance of SCCs reinforced with hybrid fiber.
- While hybridization enhances concrete's performance, its ability to mitigate fire hazards has not been explored adequately.
- Concern also abounds over the increasing global consumption of cement and its resulting ecological effects.
- The use of glass pozzolan for cement replacement specifically in SCCs is lacking, thus making it important to investigate this combination.

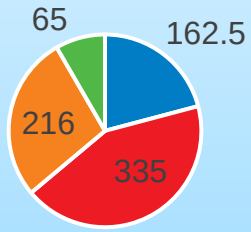
Objectives

- Review existing literature on various types of concrete, fiber dosages, and cement replacement rates.
- Formulate four concrete mixes with the appropriate amount of SF and PPF as hybrid fibers (HF) and cement replacement using GP.
- Conduct experiments to obtain an appropriate mix design that conforms to the standard design specifications.
- Study the behavior of SCC with HF and GP.
- Perform strength assessments before and after fire exposure.
- Assess the effectiveness of hybrid fiber-reinforced concrete (HFRC) against fire and draw conclusions.

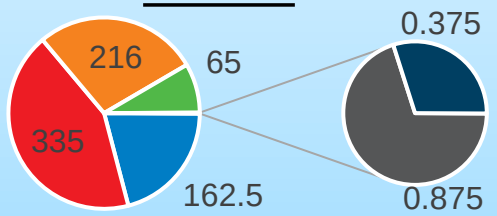
Mix Designs

- SCC mixes were designed as per ACI 237.R (2007) guidelines.
- Following several trials, a design mix was established to achieve the target slump flow of 22 in.
- Four mixes were designed:
  1. R-SCC (Regular SCC)
  2. G-SCC (SCC with GP)
  3. F-SCC (SCC with HF)
  4. FG-SCC (SCC with GP & HF)

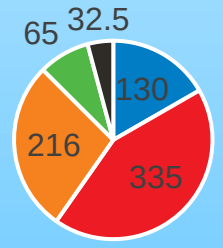
R-SCC



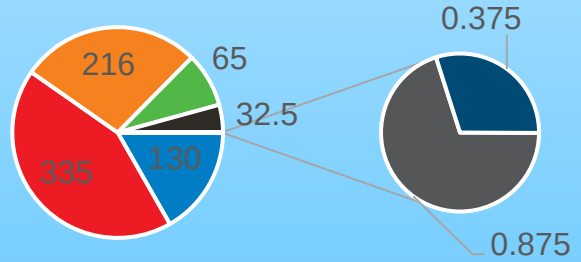
F-SCC



G-SCC



FG-SCC



Cement | Fine Aggregates | Coarse Aggregates | Water | Glass Pozzolan | Steel Fiber | Polypropylene Fiber

All the quantities are in lb.
Design volume = 0.25 yd^3
Superplasticizer dosage = 8 oz/100 lb. of cementitious material

Tests Performed

- Twelve beams, each 36 in. x 8 in. x 8 in., and 24 cylinders, each 4 in. x 8 in., were cast. Three beams and six cylinders were cast per mix.
- Thermocouples were used to measure the temperature of the cores and surfaces of the beams.

Fire Exposure of specimens: ASTM E119

Three-point bending Flexural Test: ASTM C78

Compressive Strength Test: ASTM C39

Split Tensile Strength Test: ASTM C496

Slump Test

- Slump flow was maximum for the mix G-SCC (24 in.) even higher than the regular SCC (23 in.).
- GP increased the slump of the concrete mix while hybrid fibers significantly reduced it.
- Similar results were observed before by Ghafoori et al. (2017) and Ding et al. (2012).
- Effects on PPF fibers were predominant than the SF.

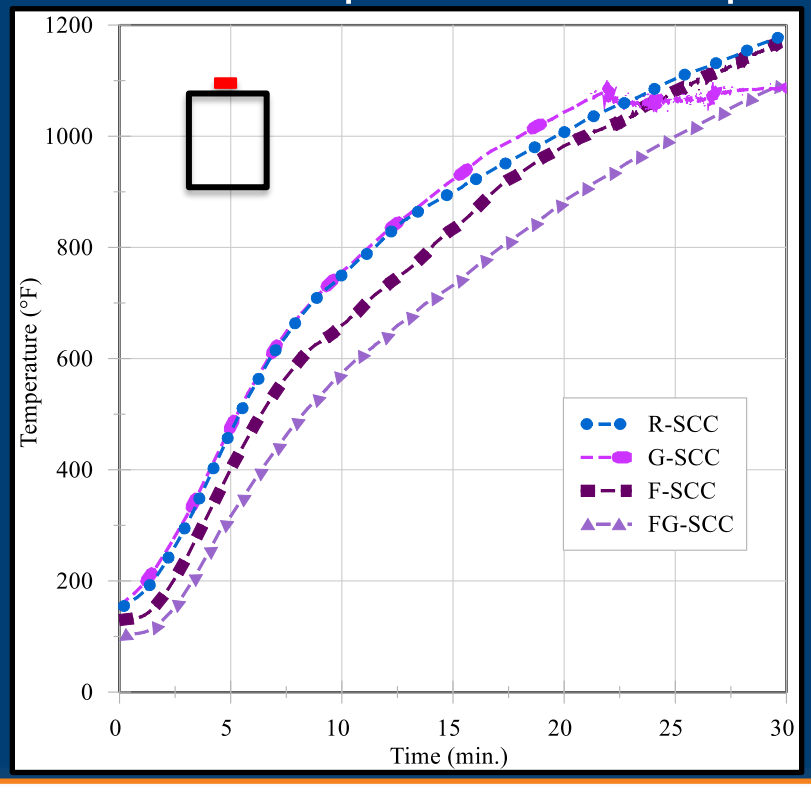
Mix designation	Batch-1 (in.)	Batch-2 (in.)	Average Slump (in.)	Comments
R-SCC	23	23	**23**	Control
G-SCC	25	23	**24**	
F-SCC	20	20	**20**	
FG-SCC	24	22	**23**	

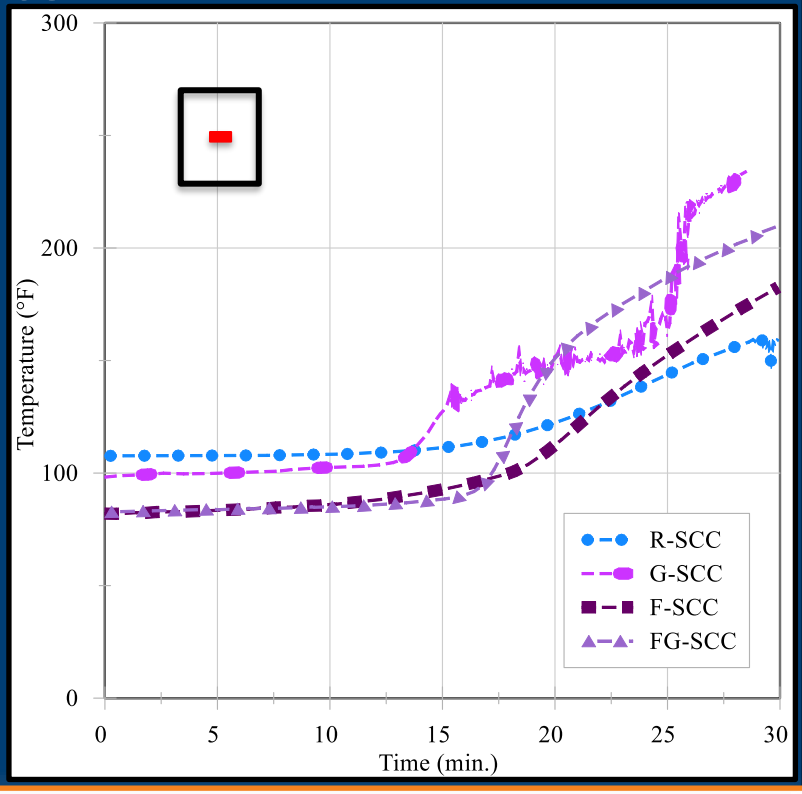
Ghafoori et al., (2016). Natural Pozzolan Contained Self-Consolidating Concrete. Fourth International Conference on Sustainable Construction Materials and Technologies, (p. 12). Las Vegas, USA.

Ding et al., (2012). Study on residual behavior and flexural toughness of fiber cocktail reinforced self compacting high-performance concrete after exposure to high temperature. Construction and Building Materials 26, 11.

Fire Test

- Mixes containing GP had maximum temperatures throughout, suggesting that the GP acts as a thermal conductor in the concrete mix. This contradicts previous results (Nasry et al., 2021).
- As previously reported (Yan et al., 2012), vapors and condensed water were observable during fire testing for mixes containing HF. Mixes with HF reported least temperatures.

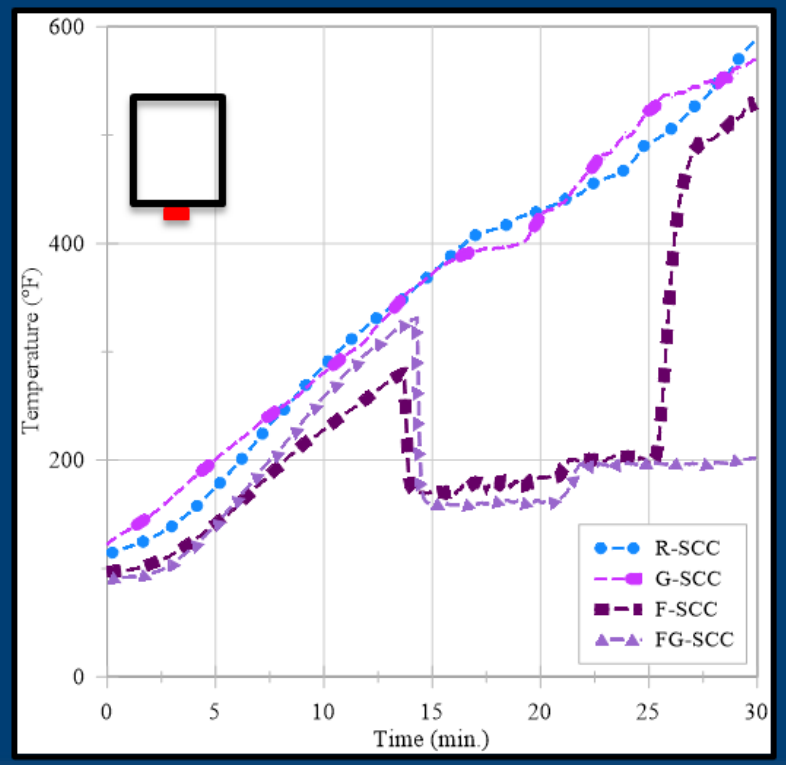


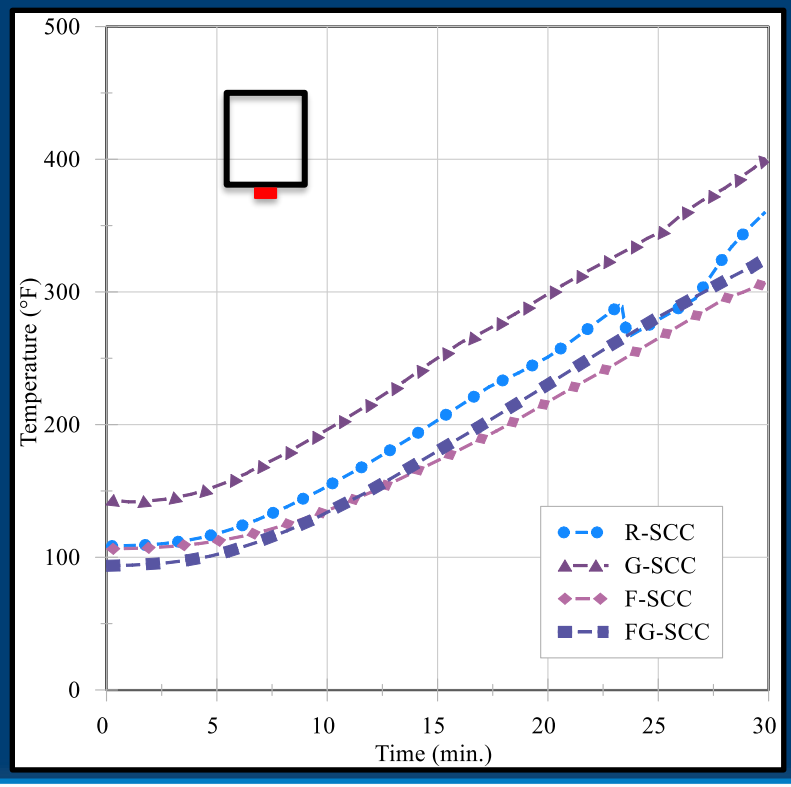


Yan et al., (2012), The Influence on High-temperature Mechanical Properties of Hybrid-fiber-reinforced High-performance Concrete and Microscopic Analysis. Applied Mechanics and Materials Vols. 226-228, 7.

Fire Test

- Polypropene fibers avoided fire spalling. Thermal cracks were observed on specimens immediately following the fire test.
- Among the cylinders, G-SCC reported the highest temperatures.
- Beam attained much higher temperature when compared to cylinders as they had higher surface area.

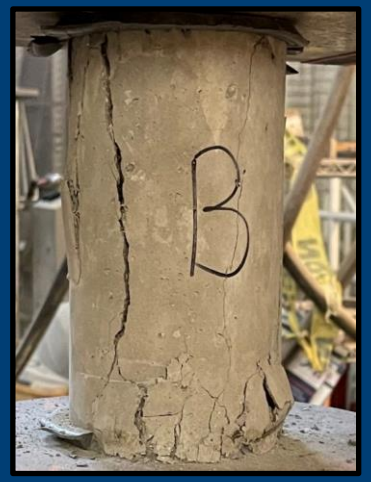


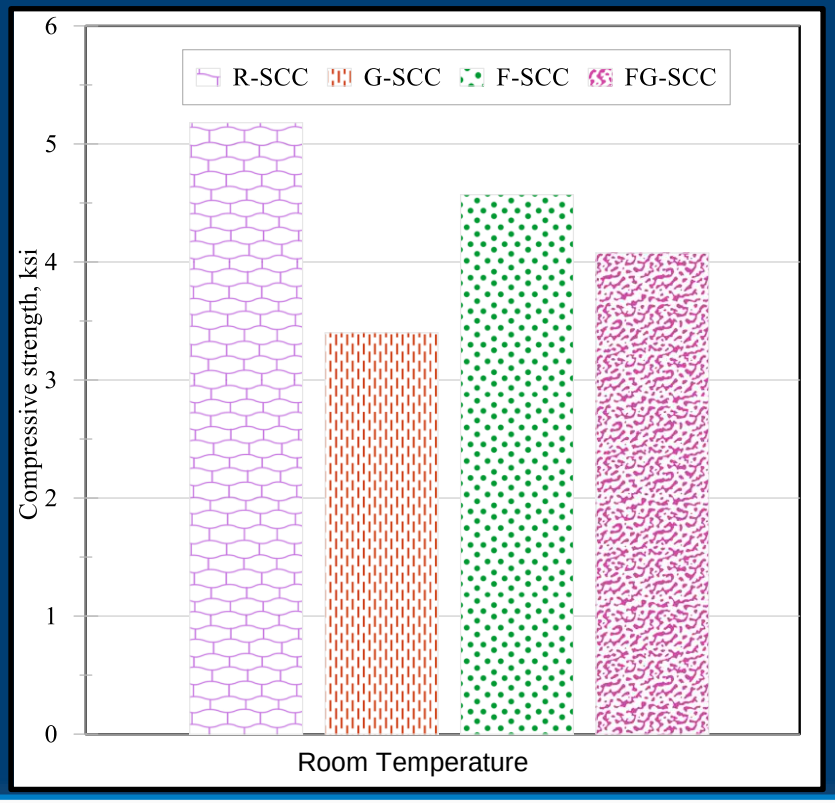


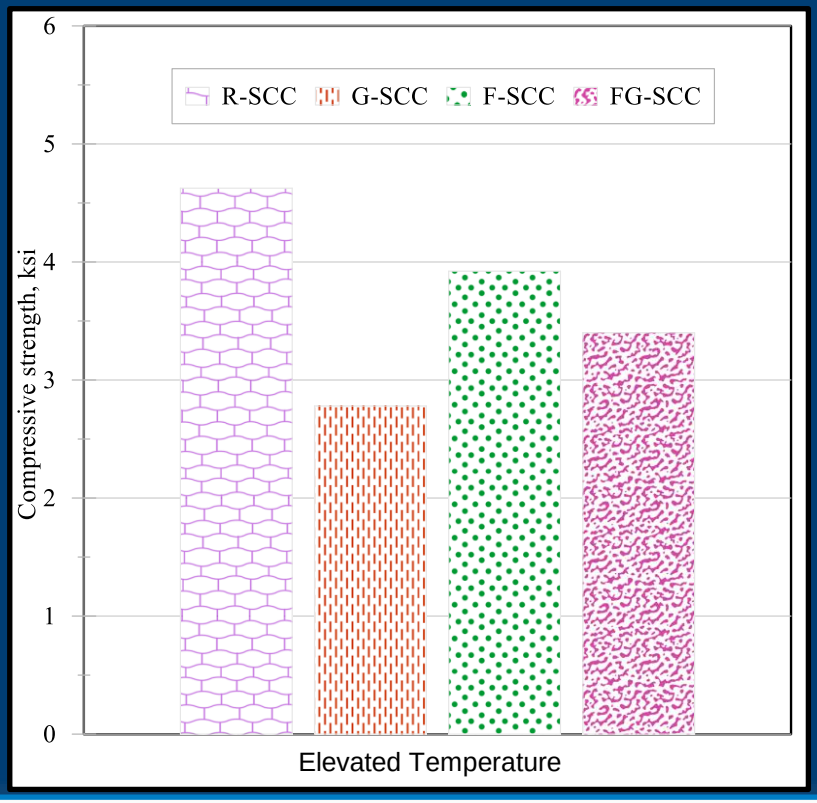
Videos from Fire Test

Compressive Strength

- At all temperatures, R-SCC had the highest compression strength, while adding GP significantly reduced it. GP only improves strength over long periods (90 days) (Zidol et al., 2020).
- After fire exposure, percentage reduction for the four mixes, R-SCC, G-SCC, F-SCC, and FG-SCC were 10%, 18%, 14%, and 16%, respectively. Failure pattern observed were similar to Type 2 and Type 3 from the ASTM C39 code

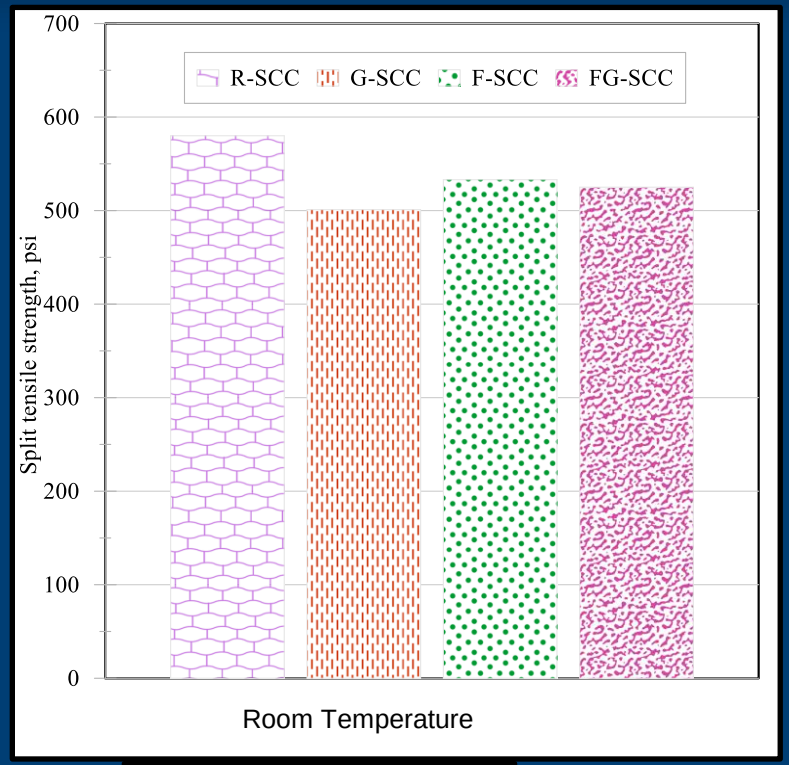


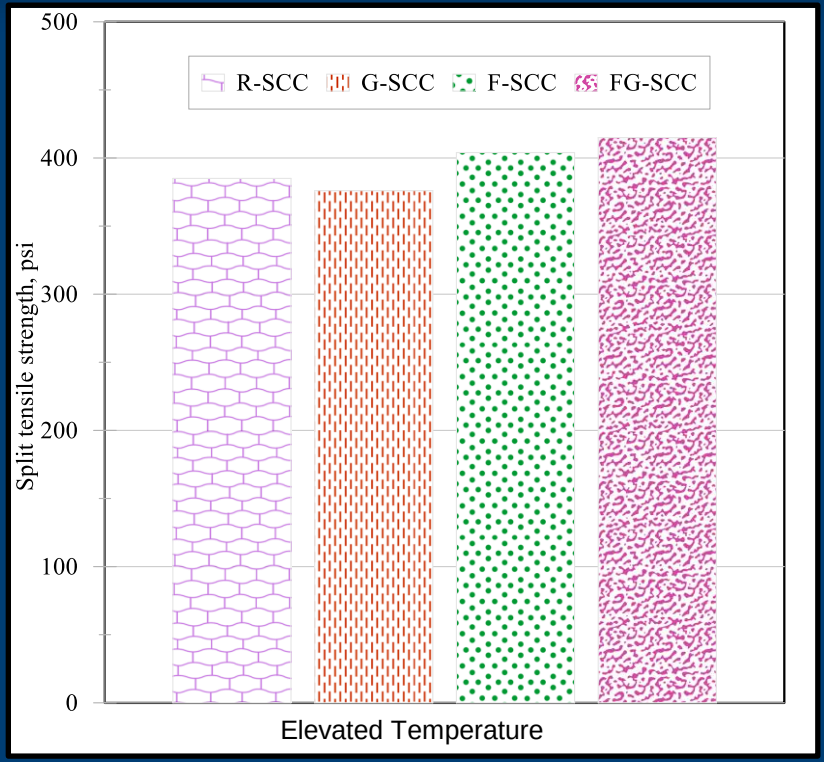




Splitting Tensile Strength

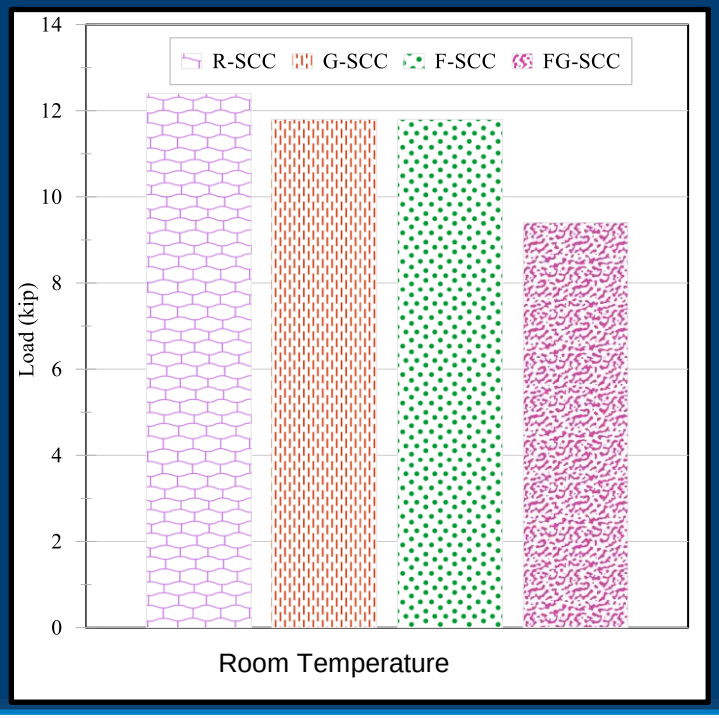
- Once again, R-SCC had the highest strength and G-SCC had the lowest.
- After fire exposure, HF elicited higher residual strength, FG-SCC being the most durable.
- HF had a positive impact on residual tensile strength.
- F-SCC and FG-SCC exhibited 21% and 24% reductions respectively, while R-SCC and G-SCC were observed to have 33% and 25% reductions, respectively.

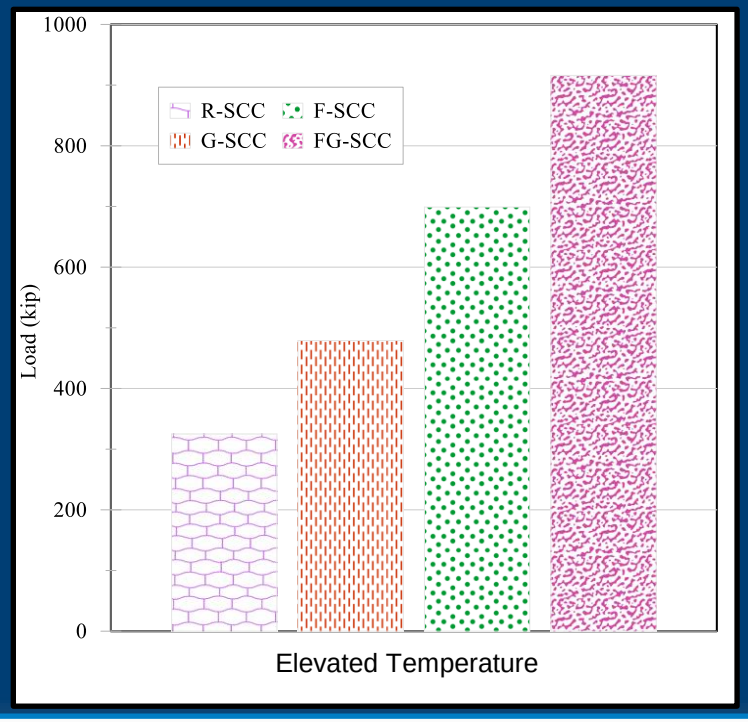




Flexural Strength

- R-SCC had the highest flexural strength, 12.4 kips. The mixture of GP and HF changed the strength significantly. The observed strength was 9.40 kips.
- F-SCC had slightly lesser strength of 11.80 kips when compared to R-SCC. This contradicted previous findings by Ding et al. (2012).
- HF benefitted the residual flexural strength and twice the strength was observed in mixes containing them.





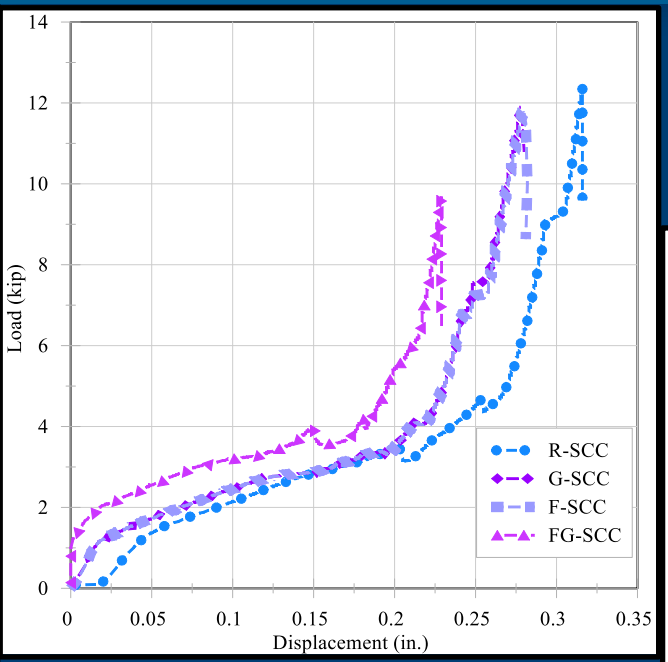
Flexural Strength

- Post-fire exposure, the FG-SCC mix demonstrated the highest residual strength (916 lb.), while R-SCC mixed observed the lowest (325 lbs.). Mixtures without HF suffered the greatest percentage loss (up to 98%).
- During fire exposure, beams failed along thermal cracks that propagated across the beam, reducing its flexural capacity to zero, causing failure.
- HF made the mixes more ductile, and no sudden fractures were observed.

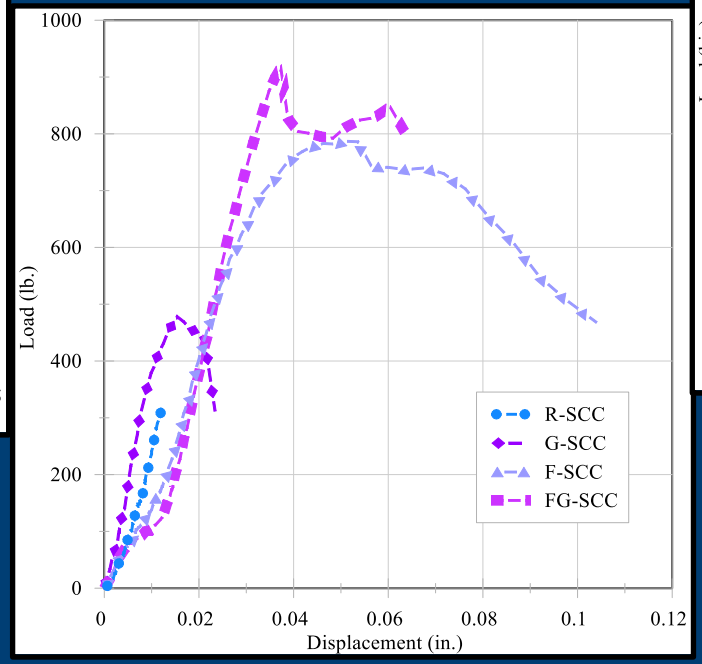
Failure modes at elevated temperature

Fracture pattern at room temperature

Flexure Strength

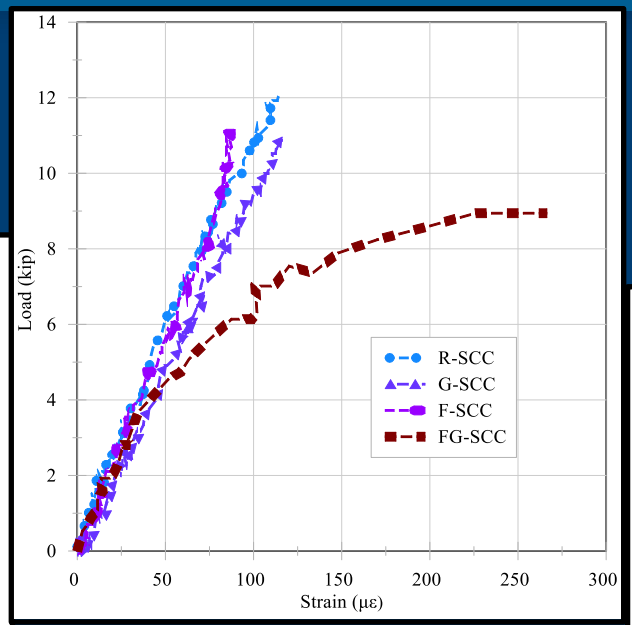


Room Temperature

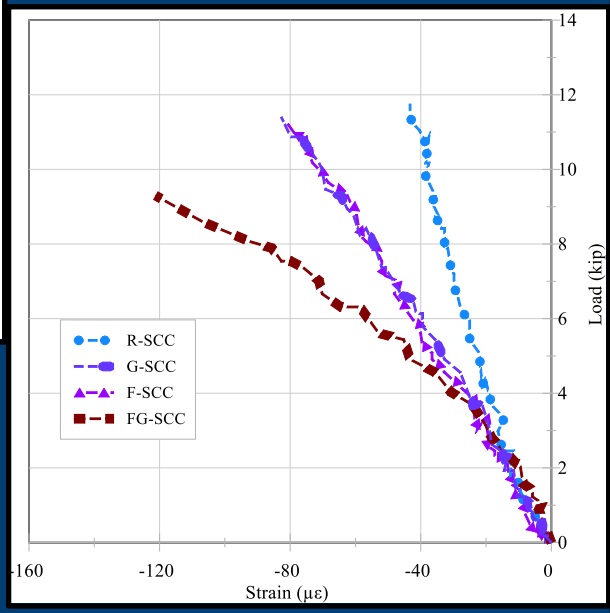


Elevated Temperature

Load vs Displacement Curves



Room Temperature



Elevated Temperature

Load vs Strain Curves

Conclusions

- Workability of SCC mixes with GP tends to be greater than with regular SCC, but HF significantly reduce the workability of SCC mixes even with glass pozzolans.
- For the top and bottom surface of the beam, the temperature of SCC with GP is similar to that of standard SCC. However, the glass pozzolan acts as a thermal conductor at the center of the beam, and SCC with GP shows a much higher temperature.
- Fibers with hybrid compositions did not aid compressive strength and tended to decrease it. The reduction was greater at elevated temperatures than at room temperatures.
- GP produced lower compressive strengths at room and elevated temperatures.

Conclusions

- At room temperature, HF did not show any improvement in compressive, split tensile, or flexural strength. However, at higher temperatures, HF held their strength well, and the strongest split tensile strength was observed for mixes that contained both HF & GP.
- The combination of HF & GP also reduced flexural strength significantly. The combination had the lowest strength of all the mixes.
- In contrast, the same combination demonstrated the highest residual flexural strength after fire exposure while the lowest residual flexural strength was observed for standard SCC. Only after fire exposure did the HF have a positive effect on split tensile and flexural strength.
- After exposure to fire, the mixes containing HF and/or GP exhibited ductile behavior, while the standard SCC exhibited brittle behavior.

Thank you

For the most up-to-date information please visit the American Concrete Institute at:
www.concrete.org