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Mechanical Properties of High-Strength Self-Compacting Concrete

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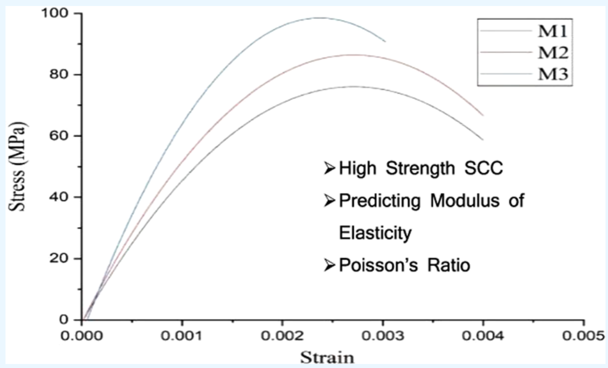
ABSTRACT: In this research work, the mechanical properties of high-strength self-compacting concrete (HSSCC) were studied. Three mixes were selected, having compressive strengths of more than 70, 80, and 90 MPa, respectively. For these three mixes, the stress−strain characteristics were studied by casting cylinders. It was observed during the testing that the binder content and water-to-binder ratio influence the strength of HSSCC, and slow changes in stress−strain curves were seen as the strength increased. The use of HSSCC results in reduced bond cracking, leading to a more linear and steeper stress−strain curve in the ascending branches as the strength of the concrete increases. Elastic properties such as modulus of elasticity and Poisson's ratio of HSSCC were calculated using experimental data. In HSSCC, since the aggregate content is lower and the size of the aggregates is smaller, it will have a lower modulus of elasticity compared to normal vibrating concrete (NVC). Thus, an equation is proposed from the experimental results for predicting the modulus of elasticity of HSSCC. The results suggest that the proposed equation for predicting the elastic modulus of HSSCC for strengths ranging from 70 to 90 MPa is valid. It was also observed that the Poisson's ratio values for all three mixes of HSSCC were found to be lower than the typical value for NVC, indicating a higher degree of stiffness.



1. INTRODUCTION

Self-compacting concrete (SCC) is a type of concrete that flows easily, consolidates, and spreads into formwork without the need for external vibration. High-strength self-compacting concrete (HSSCC) is formulated to have high compressive strengths, typically exceeding 60 MPa.[1,2] The production of HSSCC requires different materials and mix proportions compared to normal vibrating concrete (NVC), and therefore, a comprehensive understanding of its mechanical properties is essential. The use of HSSCC in construction is becoming increasingly popular due to its potential for reducing construction costs, improving workability, and improving durability. However, there is limited research available on the mechanical properties of HSSCC, and further investigation is required to fully understand its potential. In recent times, there have been several studies carried out to examine the mechanical properties of HSSCC.[3,4] These studies have shown that HSSCC has improved compressive and tensile strengths compared to conventional SCC and that its mechanical properties are influenced by factors like the type of aggregates used, curing conditions, and the type of admixtures. Numerous research works have been undertaken to analyze the mechanical properties of HSSCC, including but not limited to stress−strain behavior, elastic modulus, and Poisson's ratio.[5−8] These studies have shown that the binder content, W/B ratio, and type and size of aggregates used in the mixes significantly influence the mechanical properties of HSSCC. Zende et al.[9] investigated the stress−strain characteristics of SCC and compared them with those of normal concrete. The study found that SCC exhibited higher compressive strength and elastic modulus compared to normal vibrating concrete (NVC), as well as a lower rate of strain at peak stress. However, in other studies, the elastic modulus of HSSCC has been found to be lower compared to high-strength NVC due to the lower aggregate content and smaller aggregate size in HSSCC.[10−14] Ozkul[15] observed that the modulus of elasticity of SCC was greater than that of NVC, due to the higher compressive strength and lower rate of strain at peak stress of SCC. The Poisson's ratio of SCC was similar to that of NVC, suggesting that SCC exhibits similar lateral contraction behavior under load compared to normal concrete. This suggests that SCC may be more suitable for use in structures subjected to high stress and load compared to

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normal concrete. While both HSSCC and high-strength NVC are types of high-strength concrete, they differ in their material characteristics and performance. HSSCC is known for its excellent workability, durability, and high compressive strength. The use of superplasticizers and viscosity-modifying admixtures allows for a high-volume fraction of fine particles and fibers to be incorporated into the mix, resulting in a highly dense and homogeneous microstructure. In contrast, high-strength NVC is typically produced using a low water-to-cement ratio and a higher cement content, resulting in a highly dense and compact microstructure.[16,17]

In this study, we aim to contribute to the current body of knowledge on the mechanical properties of HSSCC by investigating its stress–strain characteristics, elastic modulus, and Poisson's ratio. Three mixes are selected with compressive strengths of 70, 80, and 90, and cylindrical specimens are cast and tested to determine the stress–strain characteristics of each mix. The modulus of elasticity of HSSCC was also obtained for each mix, and a proposed equation was developed for predicting the elastic modulus of HSSCC for strength ranges between 70 and 90 MPa. This study provides valuable insights into the mechanical behavior of high-strength self-consolidating concrete (HSSCC) and its potential application in the construction industry. This study fills this gap by providing a detailed analysis of the stress–strain behavior of HSSCC under axial loading, which can help in designing structures that are more resilient and durable. The findings of this study can be of significant value to civil engineers and construction professionals involved in designing and constructing high-performance structures.

2. EXPERIMENTAL PROGRAM

Making the right material selection is essential for producing high-strength self-compacting concrete. These materials should include cement, water, aggregate, and chemical and mineral admixtures. Chemical admixtures control the slump of the concrete, while mineral admixtures enhance its strength. In this study, ordinary Portland cement confirming to IS 12269-1987[18] was used, along with fly ash (FA) and silica fume (SF) as supplementary cementing materials acting as binders. The physical and chemical characteristics of these materials are listed in Table 1. The fineness of the mineral admixtures was determined by wet sieving with a 45 m sieve every 2 h, according to the ASTM C 430-08 (2009a)[19] standard. After 20 h, it was observed that more than 90% of the particles passed through the sieve, indicating superior performance to ordinary Portland cement.

Fine aggregate was obtained from the bed of the Krishna River in Karnataka and was locally available. The sand was black in color and met the specifications for zone II grade as defined in the IS code (IS: 383-1970).[20] The coarse aggregates (CA) were sourced from local stone crushers of 10 mm downsize. CA were made of crushed basalt stones with a specific gravity of 2.7. To enhance the strength, fly ash and silica fume were utilized as mineral admixtures, which helped to fill voids.[21] Superplasticizer, along with a viscosity-modifying agent (VMA), was used to improve the workability and decrease the W/B ratio in the concrete.[22] To produce HSSCC with a strength of up to 90 MPa, a series of trial mix proportions were developed by varying the cement content, coarse aggregate content, fine aggregate content, and W/B ratio. All mixes were evaluated to ensure that they met the characteristics of SCC as per the guidelines set by EFNARC.[23]

Table 1. Chemical Analysis of Cement, Fly Ash, and Silica Fume

chemical composition	OPC	FA	SF
SiO_2 (%)	19.3	62.63	91.9
Al_2O_3 (%)	5.2	23.34	0.7
Fe_2O_3 (%)	2.4	3.93	0.3
CaO (%)	61.2	2.04	
MgO (%)	1.25	1.3	0.1
SO_3 (%)	3.2	0.6	0.1
Na_2O (%)	0.069	0.63	0.06
density (kg/m^3)	3089	2270	2260
specific surface area BET (10^3/kg)	0.55	2.14	26.43
fineness % retained on 90 μm sieve	3%		
initial setting time in min	62		
final setting time in min	370		
specific gravity	2.96	2.2	2.15
compressive strength (MPA)			
7-day	45		
28-day	65		

Tables 2 and 3 show the trial mix proportion and the fresh properties of SCC, respectively.

Table 2. Trial Mix Proportions

mix trial no.	W/C ratio	cement (kg/m^3)	FA (%)	SF (%)	sand (kg/m^3)	CA (kg/m^3)
MF1	0.34	430	10		950	800
MF2	0.32	430	20		850	800
MF3	0.32	430	30		870	770
MA1	0.32	480		10	900	800
MA2	0.30	480		20	890	860
MA3	0.28	480		30	755	995
MC1	0.30	480	5	5	890	860
MC2	0.28	480	10	10	755	960
MC3	0.28	480	15	15	755	995
MC4	0.26	480	20	20	780	945

To check the stress–strain characteristics, elastic modulus, and Poisson's ratio of high-strength SCC, three mix proportions were selected in the compressive strength range of 70–79, 80–89, and 90–90 MPa from Table 2. The selected mix proportions are MC2 with a compressive strength of 79.57 MPa, MC4 with a compressive strength of 86.93 MPa, and MC3 with a compressive strength of 94.36 MPa.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength. The production of HSSCC requires a high powder content to achieve the desired flowability and stability. The water-to-binder ratio should also be kept to a minimum, and a high dose of superplasticizers and VMA should be used. The strength of HSSCC is greatly influenced by both the type and proportion of binder as well as the water-to-binder ratio. Figure 1 shows the average 28-day compressive strength of all SCC specimens for all mixes. The strength development was faster in the concrete specimens that contained only silica fume compared to the other specimens. This could be attributed to the use of microsilica as the mineral admixture. Table 4 gives the details of the compressive strength for all mixes with different percentages of FA and SF. Reducing the W/B ratio led to a rise in compressive strength. The greater content of binder led to higher production of

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Table 3. Summary of Test Results on Fresh SCC

sl. no.	1	2	3	4	5	6	7	8	9	10
concrete designation	MF1	MF2	MF3	MA1	MA2	MA3	MC1	MC2	MC3	MC4
Slump Flow Test										
diameter in mm	702	699	685	684	665	650	692	680	675	670
EFNARC[23] range	650−800 mm									
T-500										
time (s)	3.52	4.1	4.2	4.06	4.45	5	3.55	4.02	4.04	4.1
EFNARC[23] range	2−5 s									
V-Funnel Test										
time in (s)	9.5	9.56	10.4	10	11.32	12	9.56	10.1	10.15	11.55
EFNARC[23] range	6−12 s									
L-Box Test										
H_1 in cm	10.3	10.2	10.1	10	9.8	10	9.7	9.4	9	10.1
H_2 in cm	9.9	9.4	9	9	8.4	8.1	8.8	8.3	7.7	8.1
L-box test value in H_2/H_1	0.96	0.92	0.89	0.9	0.85	0.81	0.9	0.88	0.85	0.8
EFNARC[23] range	H_2/H_1—0.8−1									

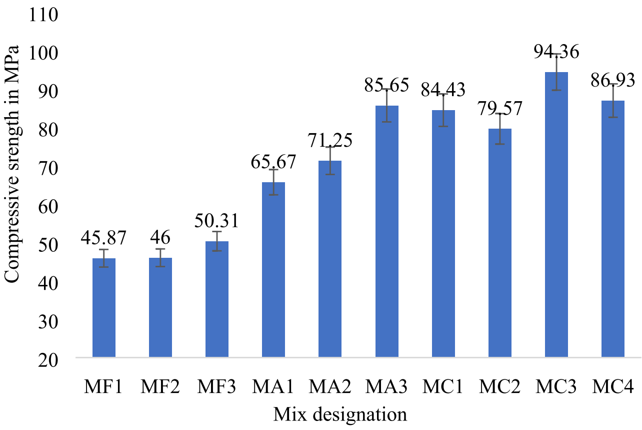

Figure 1. Compressive strength of trial mixes.

Table 4. Compressive Strength of HSSCC Mixes

mix trial no.	W/B ratio	FA (%)	SF (%)	compressive strength[a] (MPa)
MF1	0.34	10		45.87 (1.63)
MF2	0.32	20		46 (1.15)
MF3	0.32	30		50.31 (1.78)
MA1	0.32		10	65.67 (2.33)
MA2	0.30		20	71.25 (2.4)
MA3	0.28		30	85.65 (2.36)
MC1	0.30	5	5	84.43 (2.7)
MC2	0.28	10	10	79.57 (2.8)
MC3	0.28	15	15	94.36 (1.1)
MC4	0.26	20	20	86.93 (1.8)

[a]Average of three tests with standard deviation given in the bracket.

calcium silicate hydrate (C−S−H) gel, improving the physical packing of aggregate and leading to higher compressive strengths.

It was noted that HSSCC with 30% silica fume (MA3) had approximately 40% higher compressive strength compared to SCC with fly ash. The strength increase can be attributed to the incorporation of mineral admixtures that possess pozzolanic and micro-filling properties. This can also be explained by the reduction of pore size and refinement of crystals with the introduction of fine and reactive silica fume particles.[24] SF and FA in the concrete reduced the voids and increased the density by decreasing the size of the pores. The pozzolanic reaction of the FA and SF affects the compressive strength of the concrete by enhancing the microstructure of the binder paste and improving the bond between the paste and aggregate. Previous works reported that the compressive strength of concrete is reduced at early stages when fly ash is used.[24] Mineral admixtures generally have three effects on cement hydration when used with cement in concrete: first, as a filler effect to the cement, then as a pozzolanic effect, and lastly, provide additional nucleation effects during hydration.

The compressive strength of the FA mix was lower compared to that of the silica fume mixes. This was due to FA's slow pozzolanic reaction, which resulted in the dilution effect dominating at an early age in the specimens. Only a limited amount of fly ash participated in the reaction.[25]

However, at 15% replacement with SF, a significant amount of $CaOH_2$ was liberated from the hydration process, resulting in an increase in the C−S−H gel by the pozzolanic reaction due to the higher SiO_2 content in the mineral admixture. The C−S−H that formed had a lesser calcium-to-silica ratio and absorbed alkali ions from the pore solution, thus reducing the silica reaction. Additionally, the high specific surface area of SF allowed for better absorption of calcium ions, which, when removed from the surrounding cement particles, accelerated the hydration process.[26] This acceleration and the pozzolanic reaction from silica fume also activated the hydration of fly ash. It was found that using silica fume led to a reduction in the porosity of the transition zone and densified it, thus reducing the concentrations of large, oriented CH precipitates near the aggregate surfaces. It was observed that the $CaOH_2$ content in the FA mix reached its highest value after 7−14 days and decreased afterward as a result of its consumption in the pozzolanic reaction. This decrease in $CaOH_2$ content corresponded with an increase in strength due to the use of FA.

3.2. Split Tensile Strength (STS). The STS of any type of concrete is directly related to its compressive strength, but this relationship can be influenced by the type of aggregate, particle size distribution, age of the concrete, or curing processes.[27] In HSSCC, mix design method and placement also affect STS. The split tensile strength was obtained for all 10 mixes by averaging the results of three cylinders for each mix. All 10 HSSCC cylinders failed in the expected splitting failure mode.

The failure mode of different SCC specimens can be classified into three features:

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(1) Ideal failure, where the splitting crack develops at the center of the diametrical tensile zone and propagates toward the boundaries, causing failure of the specimens;
(2) central cracks with local crushing, where after reaching the maximum load, the specimens fail due to local crushing; and
(3) central cracks with other cracks, where after the development of a central crack, other cracks occur and lead to failure.

Figure 2 shows the cylinder specimen used for testing STS, and Table 5 gives the results of all of the mixes. It can be observed that SCC with silica fume mixes exhibits nearly 15% more STS compared to SCC with FA. Mix MC3 gives 19.5% more STS compared to SCC with FA alone. The increase in STS when silica fume is added can be attributed to the filling effects of fine particles in the voids of the specimens. Figure 3 shows the relationship between STS and the compressive strength of HSSCC. Previous works have shown that the STS of self-compacting concrete is lower compared to NVC.[27] This is because SCC is produced using polycarboxylate-type superplasticizers, which form large C–H crystals and ettringite that weaken the transition zone of aggregate and paste, reducing split tensile strength. Additionally, the higher binder content in HSSCC results in more microcracks, increased shrinkage, and a weaker aggregate–paste transition zone due to the decrease in surface area of the aggregates.

Figure 2. Cylinder specimens.

Table 5. Split Tensile Strengths of HSSCC

		STS (MPa)	
sl. no.	concrete designation	7-day	28-day
1	MF1	2.50	3.67
2	MF2	2.60	3.80
3	MF3	2.90	3.96
4	MA1	3.10	4.11
5	MA2	2.70	4.39
6	MA3	2.95	4.67
7	MC1	3.39	4.55
8	MC2	2.90	4.52
9	MC3	2.60	4.95
10	MC4	2.90	4.39

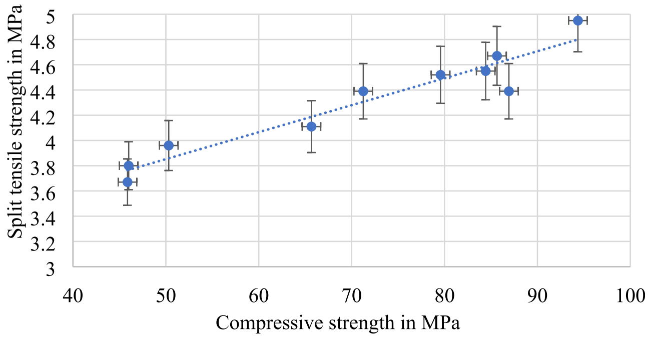

Figure 3. Split tensile strength vs compressive strength.

3.3. Stress–Strain Characteristics.

It is well known that concrete has a nonlinear stress–strain behavior, making the modulus of elasticity an important parameter to design a concrete structure. It was reported that the microcracks are present in the concrete even before the loads are applied, and these cracks increase with an increase in loading.[28] Thus, studying the stress–strain characteristics of HSSCC is critical for designing HSSCC structures. To understand the stress–strain characteristics of HSSCC, three grades of concrete were finalized, i.e., M1, M2, and M3. The apparatus to test cylinder specimens is shown in Figure 4. The stress–strain curves for all three mixes are plotted in Figure 5. During testing, it was seen that the binder content and W/B ratio influence the strength of HSSCC, and slow changes in stress–strain curves were seen as the strength increased.

It can be observed that as the compressive strength of HSSCC increases, the strain at peak stresses also increases. M3 mix has a higher strain at peak stresses as compared to M2 mix, and similarly, M2 mix has a higher strain at peak stresses as compared to M1 mix. It can also be seen that, for higher-strength concrete, the stress–strain curves are more linear as compared to lower-strength concrete. The increase in compressive strength of HSSCC also increases the linear portion of the ascending branches. The peak stresses were found to be 76.02, 86.44, and 98.46 MPa, and the strains at peak stresses were 0.00283, 0.0027, and 0.0023 for M1, M2, and M3, respectively. It is a fact that as the strength of concrete increases, microcracks in the concrete decrease. This is also the case for HSSCC. High-strength concrete has lower bond cracking, and hence, as the strength of concrete increases, the stress–strain curve becomes more linear and steeper in ascending branches.

The results of our testing showed that, for higher-strength concrete, a large decline in stress–strain curves was observed as the HSSCC reached its ultimate load, and failure occurred suddenly. This indicates that the descending part of the stress–strain curve exhibits brittle characteristics, and the sudden failure of the HSSCC specimens is due to the brittle nature of the concrete. This finding is consistent with the analysis of the literature in this area, which has shown that the descending portion of the stress–strain curve is an important parameter for ultimate strength design.[11,29] Future studies can build on our findings by exploring the factors that influence the brittleness of concrete and how these factors can be mitigated to improve the ductility and toughness of HSSCC.

3.4. Modulus of Elasticity.

The elastic modulus was evaluated at a 40% stress level, and the results are shown in Table 6. The average elastic modulus obtained from the experimental testing was 43.02, 44.07, and 45.03 GPa for mixes M1, M2, and M3, respectively. Similar to the STS of concrete, the modulus of elasticity also depends on the compressive

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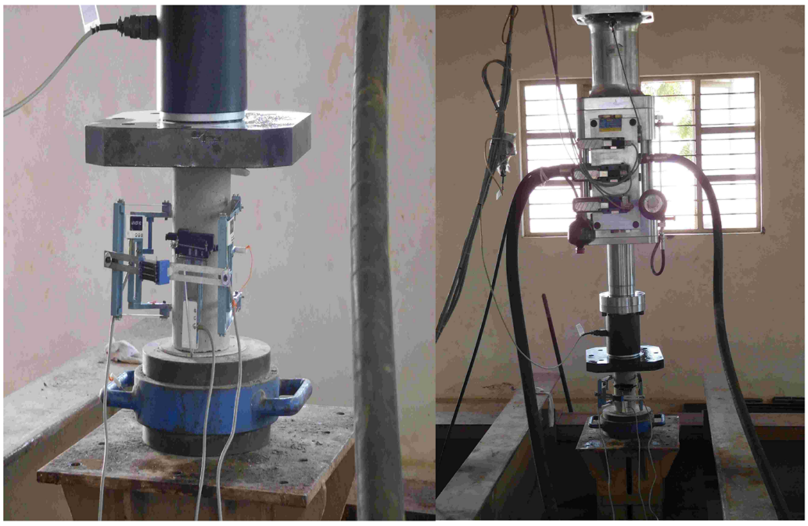

Figure 4. Apparatus to test cylinder specimens.

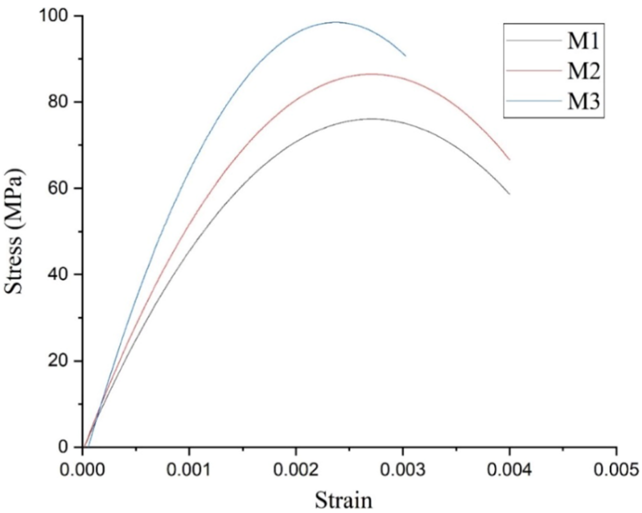

Figure 5. Stress−strain curves for all three mixes.

Table 6. Experimental Results of E_c

mix	grade of concrete (MPa)	compressive Strength f_c in (MPa)	elastic modulus E_c in (GPa)
M1	70	78.41	44.24
M1	70	79.9	43.36
M1	70	80.4	42.36
M2	80	89.6	45.03
M2	80	86.9	44.01
M2	80	84.3	43.06
M3	90	92.46	45.13
M3	90	97.35	44.47
M3	90	93.32	45.63

strength of concrete, and an increase in strength results in an increase in the modulus of elasticity. Many other factors, such as the type of aggregate, particle size distribution, type of mix proportion, concrete age, and curing process, also influence this relationship. Concrete containing a larger amount of coarse aggregate has a higher elastic modulus. It was reported that concrete tested in wet conditions has a 15% higher modulus of elasticity compared to dry conditions.[30] Thus, coarse aggregates significantly contribute to the modulus of elasticity of concrete. HSSCC tends to have a lower modulus of elasticity compared to NVC since it has less coarse aggregate. Some studies[31,32] have shown that NVC with the same compressive strength has a higher modulus of elasticity than SCC. As the strength of concrete increases, the difference in elastic modulus between SCC and NVC decreases. It was reported that EC-2 predicts the elastic modulus of HSSCC quite well and falls within the acceptable band. Therefore, it can be said that the relationship between the elastic modulus and compressive strength of SCC is still valid. The databases for the elastic modulus of concrete and high-strength concrete, as proposed by different codes and researchers, are presented in Tables 7 and 8, respectively.

Table 7. Elastic Modulus of Concrete

Sl. No	code	equation (MPa)
1.	IS-456:2000[33]	$E_c = 5000\sqrt{f_{ck}}$
2.	ACI-318-14[34]	$E_c = 4730\sqrt{f_c'}$
3.	ACI-363-10[35]	$E_c = 3320\sqrt{f_c'} + 6900$
4.	NS 3473[36]	$E_c = 9500(f_c')^{0.3}$
5.	CSA A23.3-M84[37]	$E_c = 5000\sqrt{f_c'}$
6.	EN 1992-1-1:2004[38]	$E_c = 22\,000\left[\frac{(f_{ck}+8)}{10}\right]^{0.3}$

Table 8. Modulus of Elasticity of High Strength Concrete

sl. no.	researcher(s)	equation for E_c
1.	Mostoufinezhad and Nozhati[39]	$E_c = 10.25(f_c')^{0.316}$, $(R^2 = 0.87)$ for limestone aggregate
		$E_c = 8(f_c')^{0.352}$, $(R^2 = 0.85)$ for andesite aggregate
		$E_c = 10.75(f_c')^{0.312}$, $(R^2 = 0.88)$ for quartzite aggregate
2.	Rashid, Mansur, and Paramsivam[40]	$E_c = 8900\beta(f_c')^{0.33}$, β is the coarse aggregate coefficient, applicable for $20 \le f_c' \le 130$ MPa
3.	Nassif et al.[41]	$E_c = 0.036(w_c)^{1.5}(f_c')^{0.5}$, w_c is the unit weight of concrete in kg/m^3
4.	Logan et al.[42]	$E_c = 0.000035k_1(w_c)^{2.5}(f_c')^{0.33}$, $f_c' < 124$ MPa; k_1 is the correction factor to account for the source of aggregates

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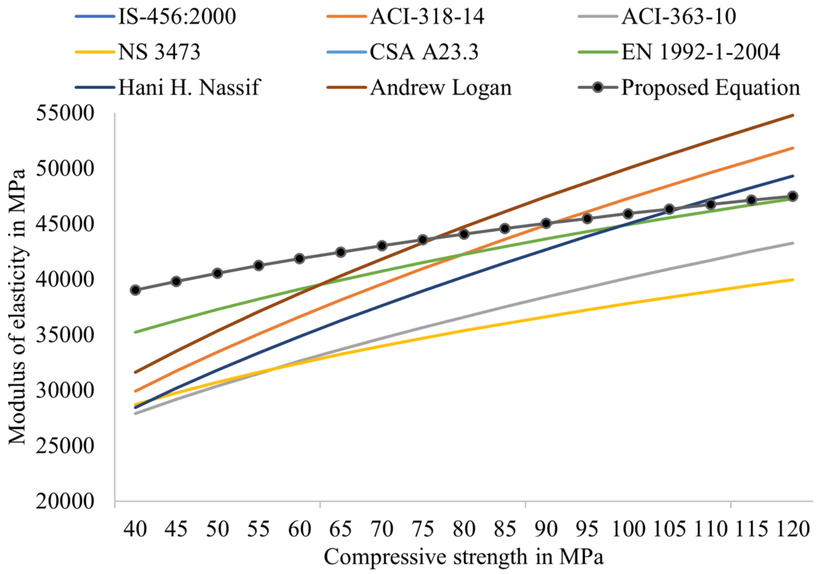

Figure 6. Comparison of modulus of elasticity.

Many researchers[39−41] have reported that the modulus of elasticity of HSSCC is lower than that of NVC for the same class of strength. All of the equations available in the codal provisions given in Table 7 either overestimate or underestimate the value of E_c. Since there is no specific equation available for HSSCC, it is essential to propose an equation to compute the modulus of elasticity of HSSCC. Previous studies[39−41] on high-strength concrete have shown that various factors such as the type and percentage of additives, curing conditions, and mix proportions can significantly affect the mechanical properties, including the modulus of elasticity. Therefore, developing accurate and reliable equations for predicting the modulus of elasticity of high-strength SCC is of great significance. The regression analysis of the experimental test results of elastic modulus provided the eq 1. This equation is limited to the HSSCC strength range from 70 to 90 MPa.

$$E_c = 18\,000 \times (f_{ck} + 8)^{0.2} \quad (1)$$

The significance of this equation is that it does not underestimate or overestimate the value of modulus of elasticity as compared to international codal provisions for high-strength concrete. The above equation is verified with different codal provisions and researchers, and the graphical comparison is shown in Figure 6.

3.5. Poisson's Ratio. Figure 7 depicts the lateral to longitudinal strain curves for all three mixes. Table 9 shows the Poisson's ratio values for all three mixes. It can be seen from the figure that the relationship between lateral strain and longitudinal strain in elastic regions under compression for HSSCC is nearly similar to NVC. It can also be seen from the figure that as the strength of concrete increases, the curve becomes more linear.

The mean values of Poisson's ratio were found to be 0.20, 0.18, and 0.17 for M1, M2, and M3 mixes, respectively. It is well known that microcracks form parallel to the directions of stress at higher stresses. Thus, at higher stress levels, an increase in transverse strains can be seen in the figures. While testing, it was observed that when the cylinders of all three grades reached their ultimate strength, Poisson's ratio increased rapidly until they failed. Thus, Poisson's ratio was measured at a 40% level of axial stress, similarly to the modulus of elasticity. The decision to measure Poisson's ratio at this point was influenced by the fact that it is a critical point in the testing process where the material begins to deform plastically and eventually fails, providing valuable information about the material's behavior under extreme loading conditions.[43]

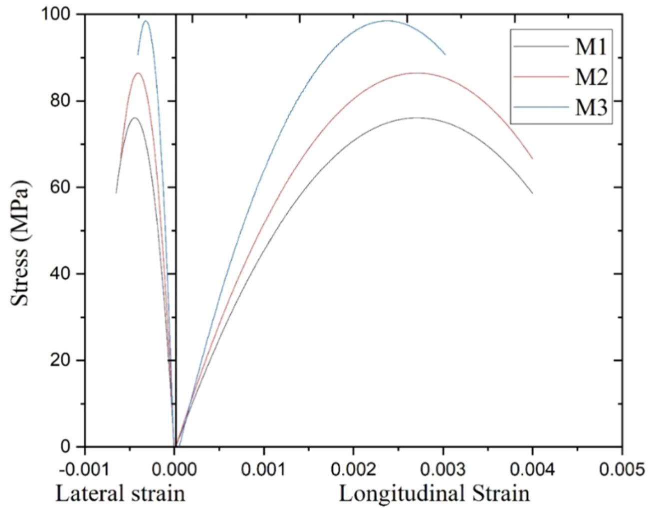

Figure 7. Lateral strain vs longitudinal strain for all three mixes.

Table 9. Experimental Results of Poisson's Ratio

mix	grade of concrete (MPa)	compressive strength f_c in (MPa)	Poisson's ratio
M1	70	78.41	0.168
M1	70	79.9	0.164
M1	70	80.4	0.159
M2	80	89.6	0.153
M2	80	86.9	0.148
M2	80	84.3	0.151
M3	90	92.46	0.136
M3	90	97.35	0.131
M3	90	93.32	0.139

3.6. Mode of Failure. While testing the cylinder specimens, the failure mode of all of the mixes was closely

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Figure 8. Failure modes.

observed. It was observed that inclined microcracks appeared and came together near the corner. With the increase in load, vertical cracks formed. It was also seen that, for the M1 mix, the first crack appeared at approximately 60% of the ultimate load, whereas for the M3 mix, it was around 75%. It was also observed that when the stress levels reached around 80%, more cracks appeared on the opposite face, and ultimately the cylinders failed, and it was also observed by different researchers.[44,45] Figure 8 shows the mode of failure of HSSCC specimens.

CONCLUSIONS

Three mixes with compressive strengths of 70, 80, and 90 MPa were studied to evaluate the stress−strain characteristics, Young's modulus, and Poisson's ratio. For each mix, three specimens were tested to obtain complete stress−strain curves of high-strength self-compacting concrete (HSSCC). The following conclusions were drawn from the current experimental program.

1. The rate of strength development in the specimens containing only silica fume was observed to be faster in comparison to the other specimens.
2. Due to the higher binder content in HSSCC, more microcracks are formed, which increases shrinkage and influences the STS of concrete.
3. The strain at peak stress and the linear portion in the ascending branches both increased as the compressive strength of HSSCC increased.
4. When the HSSCC reached its ultimate load, a large decline in the curves was observed, and failure occurred suddenly, demonstrating brittle characteristics in the descending part.
5. HSSCC has a lower modulus of elasticity compared to NVC due to the significant contribution of coarse aggregates to the modulus of elasticity.
6. An equation was proposed for predicting the elastic modulus of HSSCC, which is limited to the range of 70−90 MPa. This equation was verified with various codal provisions and researchers and did not underestimate or overestimate the value of the modulus of elasticity.
7. It was observed that the Poisson's ratio increased rapidly until failure when the cylinders of all three grades reached their ultimate strength. Also, at higher stress levels, an increase in transverse strains can be seen.

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