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Impact Of Pozzolanic Materials as A Partial Replacement of Cementitious Material on Hardened Properties of Concrete

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ABSTRACT
This experiment on study of the impact of various supplementary cementitious materials, in this research, the Pozzolanic materials used is silica fumes and fly ash on different properties of concrete. Due to the possibility that combinations of cement additions could yield more benefits for concrete than only one material, this analysis concentrated on the examination of the effects of various extra Cementitious materials on different properties of concrete. The purpose of the current study was to investigate the variation of compressive strength at 7 & 28 days of curing, elastic modulus at 28 days & split tensile strength. In this study variation of percentage of fly ash is from 0% to 75 % and maintaining silica fumes constant at 15%.Cement is partially replaced by silica fume and fly ash.

The key characteristics of cement, silica fumes, fly ash aggregate, water are mentioned in this paper. This study covers physical and chemical properties of fly ash & silica fumes. This case includes partially replacement of these Pozzolanic materials with cement. The main goal of the research is to determine if it feasible to replace Pozzolanic material partially with cement.

The change in compressive strength at 7 and 28 days and split tensile strength at 28 days is the same, however the variance in elastic modulus was entirely different. However, modulus of elasticity was discovered highest at a 30% total replacement. This replacement is done by replacing silica fumes & fly ash. Compressive strength and split strength were found most at a 45 percent replacement. The test findings show that silica fume and ash are frequently used to improve the compressive strength and lengthen the elastic modulus of concrete.

Keywords: Cement, Plasticizer, Cementitious materials Silica Fume, Fly Ash

1. Introduction

Concrete is one of the most widely used materials globally, with an annual production exceeding 25 billion tons. Historically, it consisted of cement, fine and coarse aggregates, and water. Over the years, growing demands for better strength, durability, and environmental consciousness have driven innovation, leading to the development of HPC. This engineered material is optimized for unique architectural arrangements and crowded reinforcements, offering improved performance and reduced environmental impact.

Evolution of Concrete

The advancements in concrete technology since the 1980s have focused on increasing the material's lifespan and mechanical properties. Traditional concrete has been augmented with SCMs, reducing reliance on natural resources while enhancing key characteristics. Notable developments include:

- **Durability Enhancements:** Reduced permeability and increased resistance to cracking.
- **Strength Improvements:** Better compressive, tensile, and elastic properties.
- **Sustainability Practices:** Utilization of industrial by-products like fly ash and GGBFS to reduce carbon footprints.

High-Performance Concrete

HPC is characterized by superior workability, strength, and durability. The integration of SCMs such as fly ash and silica fume improves the hydration process, resulting in a dense and refined microstructure. These materials contribute to enhanced particle packing, reduced void spaces, and stronger bonding between hydrated cement paste (HCP) and aggregates.

Role of Supplementary Cementitious Materials

- **Fly Ash:** Improves workability and reduces water demand. Its chemical composition enables long-term strength gain and durability.
- **Silica Fume:** Enhances early-age strength and minimizes permeability by refining microstructure.
- **GGBFS:** Provides sulfate resistance and reduces heat of hydration, critical for mass concrete applications.

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Admixtures and Hydration Optimization

Admixtures are vital in controlling the hydration reaction, influencing the rate and quality of cement association products. Low-heat cement combined with category C ash and silica fume enhances the mechanical and durability properties by forming dense, interconnected hydration products.

Micro structural Improvements

- **Pore Refinement:** Improved distribution of hydration products reduces porosity.
- **Aggregate Bonding:** Enhanced interfacial transition zones contribute to strength and longevity.

Environmental Impacts

The integration of SCMs addresses key environmental challenges in concrete production:

- **Resource Conservation:** Reduced dependence on natural aggregates and cement.
- **Waste Utilization:** Effective recycling of industrial by-products.
- **Energy Savings:** Lower energy requirements for SCM production compared to traditional cement manufacturing.

2. Literature Review on Ternary Blends in Concrete

Ternary blends, combining cement, ash, and silica fume, have shown significant performance advantages over cement-only mixtures. Studies demonstrate their effectiveness in enhancing concrete properties, such as resistance to chloride ion penetration, mechanical strength, and durability.

Ozkan Senegal and Mehmet Ali Tas Demir (2009) According to him for the advancement of strength, the pozzolanas were more practical for prime strength concrete because of the low water/binder quantitative relation. Concluded that the pozzolanas were more useful for the advancement of strength inside the low water/binder quantitative relation, i.e., for concrete of prime strength.

M. Sharfuddin Ahmed, Obada Kaylie, and others (2009), Researchers have conduct a quick chloride permeability test, revealed the use of ternary mixture in chloride particle penetration. study conclude that the average charge of the ternary mixture, which contains 25% fly ash and 100 percent silica fume, was significantly lower than that of the similar binary mixture.

Tahir Kemal Erden (2009), Study Conduct on high strength concrete, combining silicon oxide fume and ash in a ternary mixture. They have demonstrated that Ternary combinations almost always made it possible to obtain higher strengths than pc + SF mixtures in whatever era, provided the replacement amount by FA/ F or FA/C or S was properly chosen. They also demonstrated that the strength improvements brought about by ternary mixes were more significant at seven and twenty-eight days than at three.

Isaiah GC, Gastaldini ALG (2003), Study determined the physical and Pozzolanic effects of mineral additions on the mechanical strength of HPC. One of the causes is particle packing. Since the particle size of ash is often finer than that of cement, it follows that the tiny silica fume particles will perform better in particle packing because ash fills the intermediate particle space, which is somewhat smaller than cement.

Medhat H. Schemata and Michael D.A. Thomas (2001). A Concrete expansion brought on by the alkali-silica reaction can be reduced using a ternary mixture. They draw the conclusion that the expansion caused by ASR was successfully kept to levels below 0.04% after three years by adding sensible amounts of silicon oxide fume and ash to high-alkali hydraulic cement (HAPC) systems.

Nassim and Suksawang (2003), In their extraordinarily extensive investigation come to the major conclusion that "Combining silicon oxide fume and fly ash properties of HPC." It is actually strongly advocated that a minimum of 5% silicon oxide fume be added to the mixture in order to boost the durability of ash concrete. Additionally, relative to ACI recommendations, concrete will become more plastic.

Vein, Li and Zhao (2003) claims that blending fa with S improves microstructure and hydration rate and exhibits outstanding behavior in terms of compressive strengths over the short- and long-term as well as resistance to H2SO4 attack. Due to HSC's extensive material requirements, achieving these benefits becomes even more important for proportioning.

Key Studies and Findings

Silica Fume and Ash Performance

- The Virginia Transportation Research Council (VTRC) demonstrated that adding small amounts of silica fume to ash concrete significantly improves early resistance to chloride penetration.
- Supply and type of Cementitious materials significantly influence results.

Strength Development with Pozzolanas

- Ozkan and Demir (2009) emphasized that pozzolanas are more effective for high-strength concrete at low water-to-binder ratios.
- Ternary combinations yield higher strengths compared to binary mixtures, particularly at early ages (7-28 days).

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Chloride Permeability

• Ahmed and colleagues (2009) revealed that ternary mixtures, comprising 25% ash and 100% silica fume, exhibited lower chloride permeability than binary mixtures.

High-Performance Concrete (HPC)

• Gastaldini et al. (2003) highlighted the role of mineral additions in improving HPC's mechanical strength due to better particle packing facilitated by ash and silica fume.

• Ash contributes to long-term strength while silica fume improves early-age properties.

Resistance to Alkali-Silica Reaction (ASR)

• Schemata and Thomas (2001) demonstrated that ternary blends effectively limit ASR-induced expansion in high-alkali cement systems.

Durability and Microstructure

• Nassim and Suksawang (2003) recommended at least 5% silica fume for improving ash concrete's durability.

• Vein, Li, and Zhao (2003) reported improved microstructure, hydration rates, and resistance to acid attack with fly ash and silica fume combinations.

3. Materials

The purpose of concrete mix is to determine the ratio in which cement, water, and coarse and fine aggregates should be blended in order to provide the requisite strength, workability, and durability, as well as possible to satisfy other requirements as mentioned in standards like IS: 456-2000. A concrete combine's specification should explicitly state the materials, strength requirements, and expected durability. Given the guidelines for concrete combining styles, IS: 10262-2009. 5 mixtures are ready by replacing silica fume as 15 percent of total building material all told mixtures and V-day variation of class-C fly ash (recommended by BIS) from 15 percent to 60 percent (total replacement is from 1/3 to 75%).

3.1 Material Properties

3.1.1 Cement

Ordinary Portland cement of grade 43 is used that complied with IS: 8112-1989 (Source: Ultra Tech Cement). Cement was examined in accordance with IS 4031-1986.

Table 1 Physical Properties of Cement OPC-43

S. No.	Properties	Observed Values	Values Specified by IS : 8112-1989
1.	Normal Consistency (%))	31.5	--------------
2.	Soundness (mm)	1.8	Not more than 10
3.	Fineness % (90um I.S. Sieve)	4	Not more than 10
4.	Initial Setting Time (minutes)	58	>=30
5.	Final Setting Time (minutes)	420	<=600
6.	Compressive Strength (MPa) (i) 3 days (ii) 7 days	 26.08 34.42	 >23 >33
7.	Specific gravity	3.15	--------

3.1.2 Fly ash

Table 2 Physical Properties of Fly Ash Type (C)

S. No.	Properties	Observed Values	Values Specified by IS : 3812 (Part-1)-2003
1.	Fineness-specific surface in m^2/kg	470	320 (min.)
2.	Specific gravity	2.24	Not more than 10
3.	Lime reactivity -Average compressive strength in MPa	4.6	4.5 (min.)

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Table 3 Chemical Properties of Fly Ash Type (C)

S. No.	Chemical Properties (% by mass)	Observed Values	Values Specified by IS : 3812 (Part-1)-2003
1.	SiO_2	37.3	35 (min.)
2.	Fe_2O_3	4.8	---------
3.	CaO	29.1	---------
4.	MgO	2.5	5 (max)
5.	Na_2O	0.5	1.5 (max)
6.	SO3	2.4	3 (max)
7.	LOI	0.3	5 (max)
8.	Total chlorides	0.0	0.05 (Max)

3.1.3 Silica Fume

Table 4 Physical Properties of Silica Fume

Physical properties	Observed properties	Requirement as per IS-15388:2003	Requirement as per ASTMC 1240-03A
Fineness specific surface (m^2/kg)	20200	15000	15000
Specific gravity	2.25	------	------
Size > 45 μ	0.6%	------	10(max.)
Bulk density(kg/m^3)	525	------	500-700

Table 5 Physical Properties of Silica Fume

Chemical Properties (% By mass)	Observed Properties	Requirement as per 15388:2003	Requirement as per ASTMC 1240-03A
SiO_2	85.50	85	85
Fe_2O_3	0.85	------	-----
CaO	< 0.4	------	-----
Na_2O	0.7	1.5(max.)	-----
LOI	2.6	4(max.)	6
Moisture content	0.9	3(max.)	3(max.)

3.1.4 Fine Aggregate

Table 6 Physical Properties of Fine Aggregate

S. No	Properties	Observed Values
1.	Bulk Density (Loose), kg/m^3	1740
2.	Bulk Density (Compacted), kg/m^3	1930
3.	Specific Gravity	2.5
4.	Fineness modulus	3.2035
5.	Water Absorption%	3.5

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3.1.5 Coarse Aggregate

Table 7 Physical Properties of Coarse Aggregate (10 mm)

S. No.	**Properties**	**Observed Values**
1.	Bulk Density (Loose), kg/m³	1450
2.	Bulk Density (Compacted), kg/m³	1480
3.	Specific Gravity	2.70
4.	Free moistures%	0.1
5.	Water Absorption	0.4

Table 8 Physical Properties of Coarse Aggregate (20 mm)

S. No.	**Properties**	**Observed Values**
1.	Bulk Density (Loose), kg/m³	1500
2.	Bulk Density (Compacted), kg/m³	1550
3.	Specific Gravity	2.70
4.	Free Moisture%	0.2
5.	Water Absorption%	0.5

3.1.6 Plasticizer

Table 9 Specification of Plasticizer

Characteristic	**Unit**	**Value**	**Comments**
Density	Kg/dm3	Approx. 1.2	0.03 (+ or-)
Recommended Dosage	g	2-40	Per kg of cement
Max. Chloride Content	%	<0.10	Per weight
Max. Alkali Content	%	<6	Per weight

3.1.7 Water

Table 10 Properties of Water

S. No	**Property**	**Observed value**	**Permissible value (max.)**
1	Organic matters	150 mg/l	200 mg/l
2	In-organic matters	512 mg/l	3000 mg/l
3	Sulphate (as SO_3)	110 mg/l	400 mg/l
4	Chloride (CL)	365 mg/l	2000 mg/l for concrete work containing embedded steel and 500 mg/l for reinforced concrete work
5	PH	7.2	6 to 8
6	Total Suspended Solids	920mg/l	2000 mg/l

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3.2 Concrete Mix Design

Using a ternary system comprising OPC, silica fume, and fly ash, five combinations were created. The other five mixes are created by substituting fly ash, which ranges from 15% to 60%, for fly ash and silica fume, respectively, in place of cement in the control mix, which is one. In Table 3.11, these mixes are described in more detail.

Table 11 Mix Proportion as Per Design Mix of M-30

S. No.	Mix	Cement (kg/m^3)	S.F (% of total Cementitious material)	S.F (kg/m^3)	F.A (% of total Cementitious material)	F.A (kg/m^3)	w/c Ratio
1	R-0	446	0	0	0	0	0.36
2	R-30	312.2	15	66.9	15	66.9	0.36
3	R-45	245.3	15	66.9	30	133.8	0.36
4	R-60	178.4	15	66.9	45	200.7	0.36
5	R-75	111.5	15	66.9	60	267.6	0.36

3.3 Casting of Specimens

For compressive strength tests, 150mmX150mm cubes and 150mmX300mm cylinders were used as test specimens, respectively. Casting of the specimens followed IS: 516-1959. The specimens were evaluated for compressive strength at ages 7 and 28 days and for split tensile strength and elastic modulus at ages 28 days. The aggregates were dry with a saturated surface. The test procedures were carried out in accordance with the applicable Indian standard requirements. By weight was used for the batching.

Table 12 Specimen Details

S. No.	Mix	Curing period for CTM	No. of test specimen (150x150x150)	Curing period for Split tensile Strength	No. of test Specimen (150x300)	Curing period for modulus of elasticity	No. of test specimen (150x300)
1.	R-0	7 & 28 days	3x2=6	28 days	3x1=3	28 days	3x1=3
2.	R-30	7 & 28 days	3x2=6	28 days	3x1=3	28 days	3x1=3
3.	R-45	7 & 28 days	3x2=6	28 days	3x1=3	28 days	3x1=3
4.	R-60	7 & 28 days	3x2=6	28 days	3x1=3	28 days	3x1=3
5.	R-75	7 & 28 days	3x2=6	28 days	3x1=3	28 days	3x1=3

4. Results & Discussion

Specimens were tested for the following tests.

4.1 Workability of Fresh Concrete

The outcomes of the slump test done as per IS 1199:1959 are presented in Fig. 1. The water cement ration was kept same for the all mixes. The slump values were found in between 65 and 90 mm. When silica fume and fly ashes are incorporated, slump value starts increasing but it in limit as per IS code.

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Table 13 Slump Value for Different Mix Proportions

S. No	Mix Design	w/c ratio	Slump (in mm)
1	R-0	0.36	65
2	R-30	0.36	72
3	R-45	0.36	79
4	R-60	0.36	85
5	R-75	0.36	90

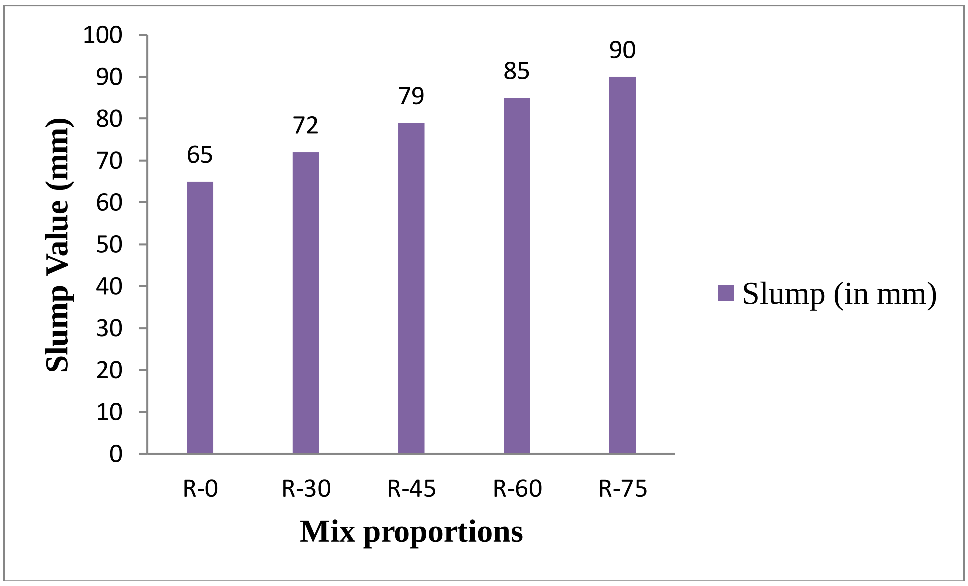

Fig. 1 Slump Value for Different Concrete Mixes

4.2 Compressive strength

The experiment was performed and specimens were checked & tested at 7 & 28 days as per IS: 516-1959. The load intensity was uniformly and continuous @5.148 kN/sec. The maximum load was recorded after the load applied continuously till the specimen failed. The compressive strength was found by taking average of 3 specimens.

At the curing periods of 7 and 28 days, the compressive strength of the mixtures is displayed in Fig. 2 for Fly ash and silica fume incorporating in conventional concrete, the results shows that the mix R-30 has a highest strength at 7 & 28 days. For the 28 days curing period R-45 mix shows the highest strength after this while increasing the percentage of fly ash strength goes on decreasing due to higher slump of concrete. As the slump value increases the density of concrete will decreases. From the results of concrete strength it was observed that the upto a certain % i.e Silica fume 15 % and Fly ash with 45 % shown the better results for 28 days compressive strength as compared to other ratios.

Table 14 Compressive Strength test Results for Different Mix Proportions

S. No.	Mix Design	7 days Compressive strength (MPa)	28 days Compressive strength (MPa)
1	R-0	18.72	34.2
2	R-30	18.61	36.3
3	R-45	17.69	38.51
4	R-60	16.81	31.23
5	R-75	12.37	20.76

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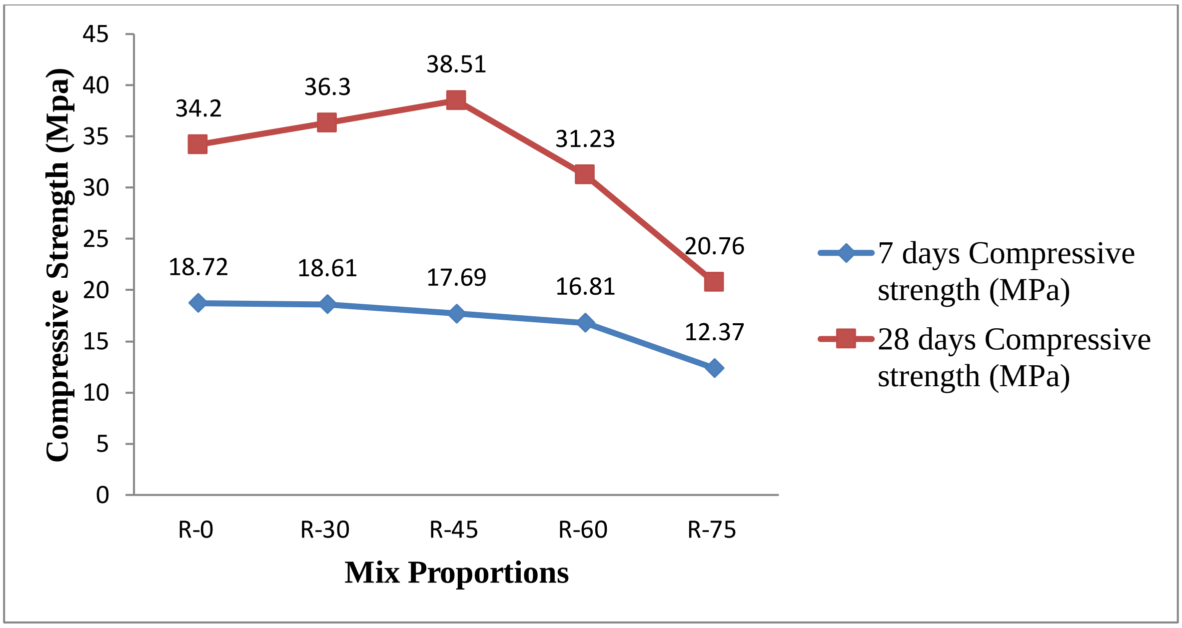

Fig. 2 Compressive Strength test Results for Different Mix Proportions

4.3 Split Tensile Strength

Fig. 3 shows that the tensile strength of concrete mixes at 28 days. The split tensile strength of concrete cylinder 150 mm x 300 mm was observed in the range of 3.48 to 2.65. Fig. 3 exhibits the highest split tensile strength observed in R-45 concrete mix, whereas the R-75 mix was detected in the minimum. The Control Mix Proportion is showed the value of split tensile strength is 3.48. From the result it is concluded that the concrete containing 15 % silica fume with 45% fly ash have highest tensile strength.

Table 15 Tensile Strength test Results for Different Mix Proportions at 28 days

S. No.	Mix design	28 days split tensile strength (MPa)
1	R-0	3.48
2	R-30	3.63
3	R-45	3.74
4	R-60	3.27
5	R-75	2.65

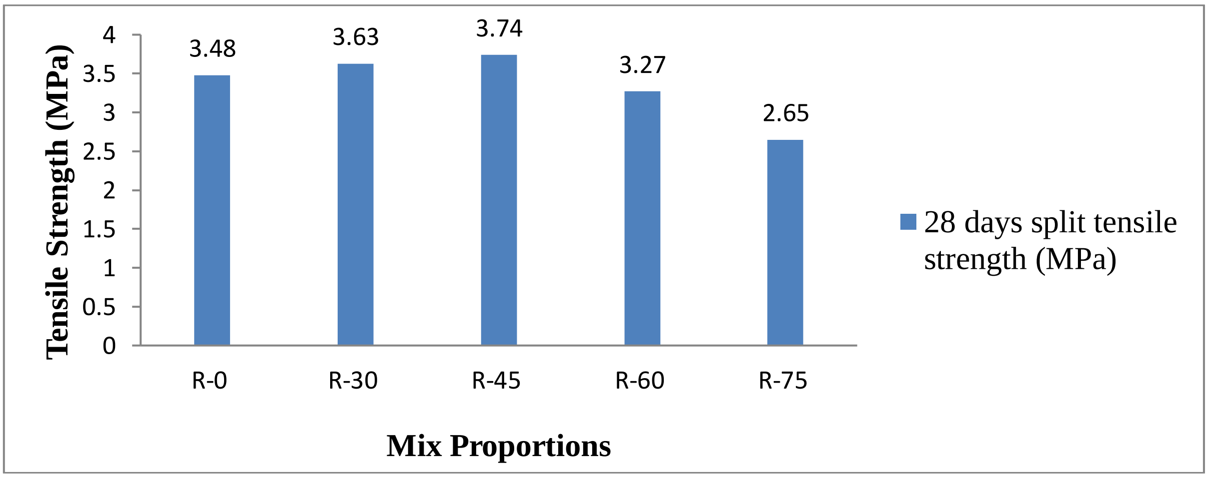

Fig. 3 Tensile Strength test Results for Different Mix Proportions

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4.4 Modulus of Elasticity

Modulus of elasticity of various mixes was observed from stress-strain curve. The results shows that the modulus of elasticity of concrete R-30 mix has highest value. As the fly ash content increase it decrease the modulus of elasticity.

Table 16 Tensile Strength test Results for Different Mix Proportions at 28 days

S. No.	Mix designation	Modulus of elasticity at 28 days (Gpa)
1	R-0	33.943
2	R-30	37.066
3	R-45	36.515
4	R-60	34.257
5	R-75	29.255

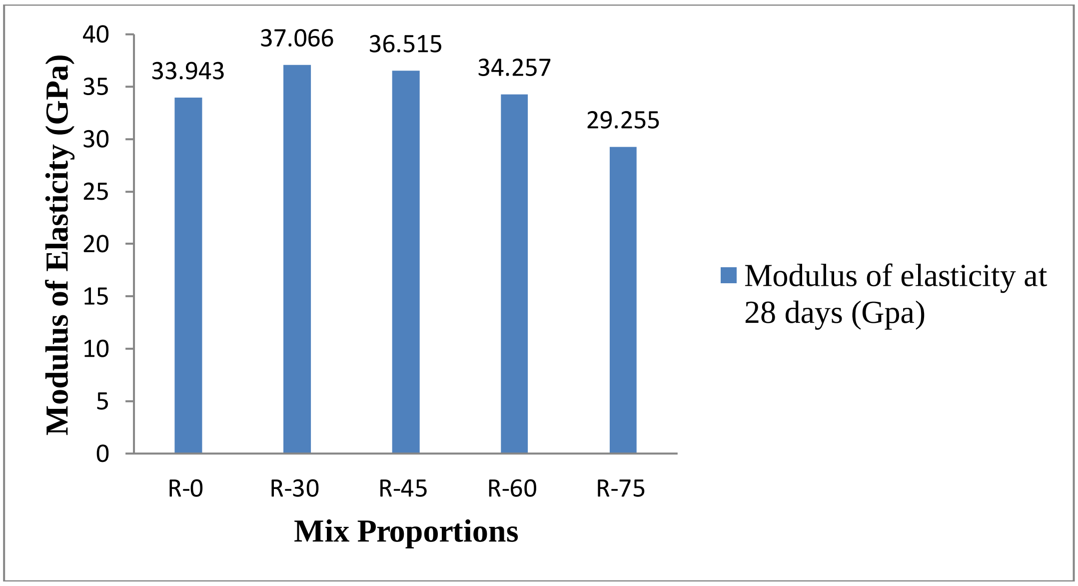

Fig. 4 Modulus of Elasticity for Different Mix Proportions

5. Conclusions

The main objective of this experimental design study i.e. replacement of cement with Silica fume and fly ash to obtain the experiment basis results with the slump, compressive strength, split tensile strength and modulus of elasticity of concrete mixes. Based on the outcomes found, the following conclusion can be drawn:

1. The 7-day compressive strength of the mixes was observed for different mix proportions and concluded that for R-30 the strength was increased after this the compressive strength goes on decreasing. The rapid decrease in compressive strength for 7 days was observed for R-75.
2. At 28 days of curing, the maximum compressive strength was discovered with 45% total replacement (15% silica fume and 30% fly ash). It might be brought on by a decrease in porosity as well as the transformation of calcium hydroxide into CSH gel by silica fume and fly ash. As more fly ash is added, the compressive strength begins to decline.
3. At 28 days of curing, the maximum tensile strength was discovered with 45% total replacement (15% silica fume and 30% fly ash). After which the strength goes on decreasing. From results shown it was concluded that the mix R-45 have a better result and sufficient to carry design loads.
4. The modulus of elasticity was found from the stress-strain curve and it was observed that for the mix R-30 highest value is obtained.

Hence, from the above outcomes, it may be concluded that 30 % of cement may be replaced by R-30 mix (15 % of Silica fume and 15 % of fly ash.

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