

# INVESTIGATING THE CRACK PROPAGATION RESISTANCE OF NANO CONCRETE THROUGH FRACTURE MECHANICS

*Kalpesh Laljibhai Kapadiya<sup>1</sup>, Dr. Sanjay Joshi<sup>1</sup>, Dr. Ajaysinh Vaghelas<sup>1</sup>, Parag Rameshbhai Savsani<sup>2</sup>*

<sup>1</sup> Department of Civil Engineering, R. K. University, Rajkot, Gujarat, INDIA

<sup>2</sup> Department of Civil Engineering, Dr. Subhash University, Junagadh, Gujarat, INDIA

**Abstract.** In the concrete treatments, small cracks are beginning developing inside. As a result of temperature and stress variations during extraction, the fragments will enlarge and unite to form some noticeable cracks. Concrete constructions may suddenly shatter as a result of cracks spreading. The study focuses consideration of the inspiration of additives on the properties of fracture in high-performance concrete with additives (HPCA) as a foundation for the effective application of building structures. Compared to traditional concrete, HPCA has better mechanical qualities and durability. The highly responsive nanoparticles significantly improved concrete performance. Portland cement has been replaced with nanoparticles at different percentages of weight to create HPCA mixtures. The impact of nano silica (nS) and nano alumina (nA) on the appearance of fracture and crack extension resistance of HPC during the process of entire fracture will be assessed in this research. Based on the softening laws and outcomes of the bending test of three-point of concrete material along with grooves, the resistance of crack extension of HPCA was determined. The crack mouth opening displacement versus load relationship curves (P-CMOD) represent the ultimate result. Compressive strength and additional mechanical properties have been determined within the model. Ultimately, the P-CMOD curves are used to analyse and compute the fracture parameters and features of HPCA utilizing nano particles.

**Keywords:** Concrete, Nano-particles, Fracture, Characterizations, Durability, Mechanics

# ИССЛЕДОВАНИЕ СОПРОТИВЛЕНИЯ РАСПРОСТРАНЕНИЮ ТРЕЩИН В НАНОМОДИФИЦИРОВАННОМ БЕТОНЕ НА ОСНОВЕ МЕХАНИКИ РАЗРУШЕНИЯ

*Калпеш Лалджибхай Кападия<sup>1</sup>, Санджай Джоши<sup>1</sup>, Аджайсинх Вагелас<sup>1</sup>, Парат Рамешбхай Савсани<sup>2</sup>*

<sup>1</sup> Кафедра гражданского строительства, Университет Р. К., Раджкот, Гуджарат, ИНДИЯ

<sup>2</sup> Факультет гражданского строительства, Университет доктора Субхаша, Джунагадх, Гуджарат, ИНДИЯ

**Аннотация.** В процессе обработки бетона в нем могут появляться небольшие трещины. В результате колебаний температуры и напряжения при прекращении обработки микротрещины увеличиваются и объединяются, образуя заметные трещины. В результате распространения трещин бетонные конструкции могут внезапно разрушиться. Данное исследование посвящено рассмотрению влияния добавок на параметры разрушения высокопрочного бетона с добавками (НРСА) как основы для эффективного применения в строительных конструкциях. По сравнению с традиционным бетоном, НРСА обладает лучшими механическими свойствами и долговечностью. Высокочувствительные наночастицы значительно улучшили характеристики бетона. Для создания смесей НРСА портландцемент был заменен наночастицами в различных весовых процентах. В данном исследовании было оценено влияние нанокремнезема (nS) и наноглинозема (nA) на появление трещин и сопротивление раскрытию трещин в НРС в процессе полного разрушения. На основе законов разупрочнения и результатов испытания на трехточечный изгиб бетонного образца с вырезом было определено сопротивление расширению трещин в НРСА. Получены кривые зависимости смещения устья трещины от нагрузки (P-CMOD). В рамках модели были определены прочность на сжатие и дополнительные механические характеристики. Кривые P-CMOD использованы для анализа и расчета параметров разрушения и характеристик высокопрочного наномодифицированного бетона (НРСА).

**Ключевые слова:** Бетон, наночастицы, разрушение, характеристики, долговечность, механика

## 1. INTRODUCTION

Concrete is the greatest frequently employed construction substantial and heterogeneous composite material made of cement, water, sand, and stones. When concrete is moistened and mixed with various fluids while in use, a lot of microcracks are created. Microcracks will continually form, enlarge, and penetrate when under load. The internal microcracks in concrete ultimately broaden and seep through, causing the material to fracture. Three stages can be observed in the propagation of concrete cracks under uniaxial compression: unstable crack growth, stable crack growth, and crack initiation. The advancement of concrete crack propagation research has important implications for damage-warning techniques and safety evaluations in numerous construction structures. Inserting nanoparticles to high-performance concrete greatly enhance the material's durability and mechanical qualities. Compared to silica fume materials in micro-meter sizes, HPC has used silica material in the size of nano-meter is seen as a novel development. Ultrafine silica particles have a size of nano-meters aid in launching reactions of pozzolanic, uneven  $\text{Ca}(\text{OH})_2$  elements has been rejected and result in gel product of pozzolan at the performance has high. According to (Lam et al. 2020) [8], the mechanical characterizations like strength of compression, flexural, modulus of elasticity and deformation stress of HPC with NS has been improved. The impression of nano-silica on the properties of fracture in concrete was highlighted by recent studies utilizing NS in HPC (Khaloo et al. 2016; Zhang et al. 2017; Vivek et al. 2021) [7,20,19], but no particular experiments were conducted for evaluation. Most of the structures of concrete was affected by the areas of fracture mechanics Mindess (2002) [12]. Concrete that contains silica fume have better fracture properties than usual ones (Ricardo and Marta, 2006). A new approach of measuring the fracture using artificial failure surfaces of concrete were performed and analysed by (Mechtcherine and Müller, 2021)

[10] The transition of interface zone of quality between aggregate and mortar is enhanced by silica fume, which also improves the C-S-H structure and uniformity. When silica fume is used, fracture energy, fracture toughness, and length characteristics all grow more, and the brittleness of HPC tends to diminish. The properties of fracture are very crucial for the endurance and safety structures of HPC represented by (Zhang et al. 2017) [20]. The quality of fracture in concrete's are impacted when pore structures in HPC are improved through the use of chemical and mineral admixtures. These results are increasing the mortar-aggregate density transition zone of interface. The consistency performance of mortar will be enhanced by silica ultrafine particles, which also increase the cohesiveness between aggregate and cement particles and greatly improve the concrete's fracture characteristics.

The microstructure and fracture behaviour of concrete will both be enhanced by the presence of ultrafine particles. Because of the high strength properties of HPC concrete, brittle fracture occurs more often and often passes through the coarse aggregate rather than along the aggregate boundary as it would in regular concrete. The mechanical properties of normal concrete have low compared to HPC. The slope curve's downward (after the apex) steepens for HPC. This demonstrates that HPC is more prone than regular concrete to sustain unexpected deterioration.

The main focus of the essay is centered on figuring out HPCA's mode I fracture characteristics and parameters. To ascertain the fracture parameters of HPCA, a unique testing procedure in accordance with RILEM was used, which involved regulating the open displacement of the crack mouth. In accordance of IS method as per 10262-2019 for M40 grade guidelines, the five mixed proportions of HPC with contents of 0.5%, 1%, 1.5%, 2%, and 2.5 % were computed for the component design to be used in the experiments. It was determined how the nA and nS contents affected the HPC's

fracture properties. The fracture mechanics approach was applied to assess the experimental findings and determine the properties of HPCA beams' resistance to crack extension.

## 2. RELATED WORKS

Van Mier, Jan GM (2012) [18] asserts that ultrafine particles will dramatically alter how concrete behaves during the fracturing process. The deformation of stress curve illustrates an improvement in ductility, particularly as the curves' post-peak slope gradually declines. The inclusion of ultrafine NS particles helps to bridge broken surfaces, which explains why the toughness has improved. The fracture quality has minimum of normal concrete compared with silica fume of concrete (Einsfeld et al. 2006) [4]. The administration of silica fume optimizes the standardization and structure of C-S-H gels, as well as the functionality of the ITZ as a of mortar and aggregate. When utilizing silica fume, the characteristics of toughness, length, and fracture energy are increased. HPC brittleness tends to diminish. Concrete's fracture characteristics are impacted when the ITZ of mortar and aggregate is made denser by chemical and mineral admixtures in HPC (Zhang et al. 2014) [21].

Additionally, some research employing HPC with ultrafine nano particles asserted, when hardened the mortar performance and consistency has been continuously improved. Increasing the cohesiveness between the aggregates and cement particles also considerably increases the fracture toughness of concrete (Chithra et al. 2016) [3]. Concrete's microstructure and fracturing behaviour are greatly improved by ultrafine particles. (Quercia et al. 2013) [13] indicated that the inclusion of fine material significantly alters the way that concrete fractures. The enhanced ductility of the ultrafine concrete component is indicated by the load-deformation curve. In comparison to the concrete without fine particles, slope curve of

post-peak is lower Bianchi (2014) [2]. Bridging surfaces are broken at maximum in the ultrafine particles' presence accounts for an improved toughness. To comprehend the connection between ultrafine particles and the behaviour of concrete cracks, some empirical research has also been carried out. Overall, the findings indicate that the ultrafine mineral composition appears to have an impact property of concrete fracture (Zhang et al. 2017).

(Torabian Isfahani et al. 2016) [17] investigated the impact of varying nanosilica dosages on the compressive strength and durability of concrete with different water/binder ratios. They evaluated concrete properties by measuring water sorptivity, apparent chloride diffusion coefficient, electrical resistivity, and carbonation coefficient. Results indicated that compressive strength improved significantly for a water/binder ratio of 0.65 with the addition of nanosilica, while no significant change was observed for a ratio of 0.5. Water sorptivity decreased with increased nanosilica only for a water/binder ratio of 0.55. A 0.5% nanosilica addition reduced the chloride diffusion coefficient for water/binder ratios of 0.65 and 0.55, but higher dosages did not yield further improvements. Electrical resistivity increased with 0.5% nanosilica across all ratios and with 1.5% only for a water/binder ratio of 0.5. Carbonation coefficient changes were minimal, with some adverse effects noted for a ratio of 0.65. Microstructural analysis through techniques such as X-ray diffraction and scanning electron microscopy provided additional insights, showing that nanosilica's effectiveness was more pronounced in lower strength mixes.

(Mahender et al. 2017) [9] explored using waste plastics and rubber as partial replacements in concrete, with incremental 5% substitutions in both fine and coarse aggregates. Concrete cubes and cylinders were tested at 7 and 28 days and compared with specimens containing 0% waste materials. The study found that incorporating

waste plastics and rubber was effective for constructing rigid pavements, sewers, tennis courts, and walkways, resulting in a reduction in the overall pavement thickness. Despite advancements in concrete technology, the investigation of crack propagation resistance in nano concrete using fracture mechanics remains underexplored. Existing research primarily focuses on the general mechanical properties and durability of nano concrete, often neglecting a detailed analysis of its fracture behavior. Current studies do not sufficiently address how nanoscale additives influence crack initiation, growth, and propagation under various stress conditions. There is a lack of comprehensive understanding of the interaction between nano materials and concrete matrix at the microstructural level concerning crack resistance. This gap highlights the need for targeted research that employs fracture mechanics principles to evaluate the effectiveness of nano additives in enhancing the crack propagation resistance of concrete, which could lead to more resilient and long-lasting construction materials.

**3. MATERIALS AND METHOD**

**3.1 Materials**

The Portland cement contains aggregates of coarse basalt with 12.5 mm  $D_{max}$ , superplasticizer, nano-silica, nano-alumina and fine aggregates with a module 2.7 mm. The Adnano technologies NS product has a surface area of  $200 \pm 25 \text{ m}^2/\text{g}$  and diameters of 5-50 nm, was used for the research. Nano alumina (nA) and nano silica (nS) particles were utilized as additives in concrete beams.

**3.2 Mix Proportion**

An IS method as per 10262-2019 for M40 grade method is used to design the compressive strength of HPCA for 49 MPa (Sivasankaran et al. 2019) [16]. Mixtures with 0.5%, 1%, 1.5%, 2%, and 2.5% nano particles ratios were made for the experimental test. The ratio has chosen and modified combinations in accordance with the recommendations Fédération-internationale-du-béton (2008) [5]. A mixture of the percentage of HPC with additives as depicted in Table 1.

*Table 1. Different proportion of additives*

Mix Mode (nA and nS)	0.5%	1%	1.5%	2%	2.5%
Cement (kg)	543.31	540.5	534.8	530.9	525.7
Fine Aggregate (kg)	673.2	672.4	671.6	670.8	669.8
Coarse Aggregate (kg)	1049.75	1049.75	1049.75	1049.75	1049.75
Nano-Alumina	0.5	1	1.5	2	2.5
Nano-silica	0.5	1	1.5	2	2.5
Superplasticizer	5.32	6.42	7.51	8.21	9.25
Water	154.67	154.67	154.67	154.67	154.67
Water/Binder	0.27	0.27	0.27	0.27	0.27

**3.3 Preparation of sample**

Before mixing, material components including cement, fine and coarse aggregate, and superplasticizer are ready for measurement. To make sure that the additives are distributed equally throughout the mixture, they are

specifically combined with half of the water needed and vigorously agitated. Following material preparation, the specimen mixing process is carried out in accordance with the protocol depicted in Figure 1.

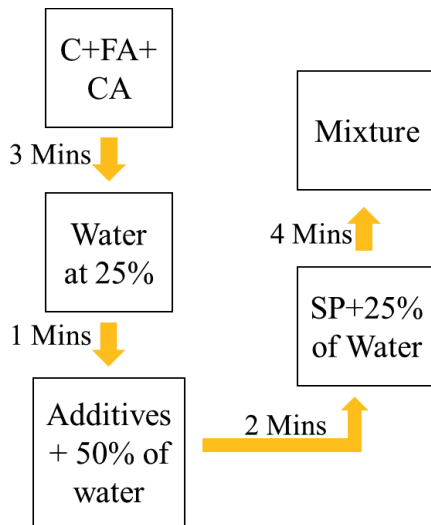


Figure 1. HPCA preparation procedure

As seen in Figure\_2, the concrete design with notch has been created. Table 2 represents the different sizes of beam used for this research work.

Table 2. Different size of beams

Dimensions	Length (L) mm	Width (B) mm	Depth (D) mm	Notch Size (a) mm
Small	151.62	57	57	11.4
Medium	303.24	57	114	22.8
Large	606.48	57	228	45.6
Ratio of a/d 0.2				

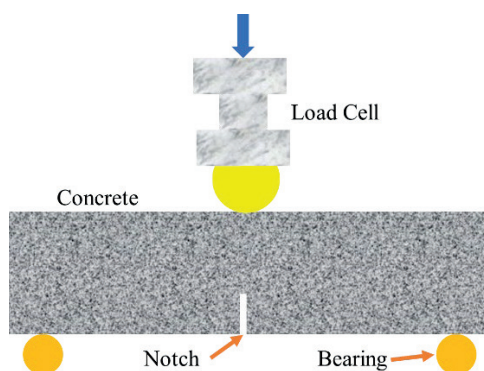


Figure 2. Specimen used for fracture test

### 3.4 Experimental Methods

To ascertain the concrete's fracture parameters, conduct an experiment using notch with

bending beam of 3-point apparatus. A test procedure has illustrated in Figure\_3. The fracture test uses specimen displacement as opposed to load control, establishing it separate from the stronger test and other mechanical evaluations. The Control experiment machine is used to perform all three-point bending experiments in a closed-loop setting. In Figure\_3 represented the linear variable differential transformer (LVDT) has measured the outcome of load and beam displacement and crack mouth open displacement (CMOD) as determined using extensometer were the parameters measured during the experiment.

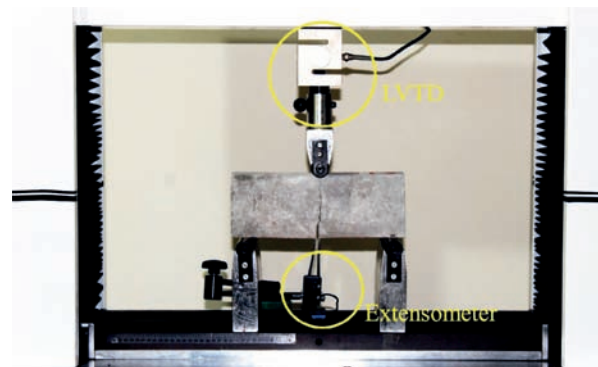


Figure 3. 3-Point bending test of HPCA specimen

According to FMC's recommendations Recommendation, RILEM Draft (1985) [15], studies must be carried out to ensure that the mid-span displacement increases at rate of consistent is 0.2 mm/min. Nonetheless, the analysis suggests that this condition could be modified slightly. An experimental test was carried out CMOD control rather than mid-span displacement control.

#### 3.4.1 Test of Determining Fracture Energy

The deflection of beam is monitored using linear variable differential transformer (LVDT) located at center of the concrete beam. The maximum load was attained 30 seconds after the loading began selection of velocity loading. A rate of loading chosen is 0.25 mm/min. Next, a curve of load-deflection (F- $\delta$ ) was drawn, and under the curve area was represented by the energy symbol "Wo." The following expression can be used to

determine the GF (N-m) (AlKhatib et al. 2020; Rakesh et al. 2021) [1,14].

$$G_F = W_0 + mg \frac{\delta_0}{A} \quad (1)$$

where  $W_0$  = load-deflection area curve (N-m)  
 $m$  = beam of mass between the supports (kg)  
 $g$  = gravity acceleration  
 $\delta_0$  = beam deflection at final stage (m)  
 $A$  = beam cross sectional area exclusive notch (m<sup>2</sup>).

### 3.4.2 Test for Determining $K_{IC}^S$

The test procedure represented by (Jenq et al. 1985) [6] was utilized to determine  $K_{IC}^S$ , and it involved a closed-loop testing apparatus with crack mouth opening displacement (CMOD) control. The clip gauge was used to monitor the CMOD. Throughout the test, the applied load and the CMOD were continually recorded. There were two loading and unloading steps in the test protocol. The applied load was manually lowered (also known as unloading) once the load passed the maximum load and was roughly 95% of the peak load. The first process involved loading until the peak load was attained. Reloading was used when the applied load was lowered to zero. About a minute was needed to complete each loading and unloading cycle. For the test, a single loading-unloading cycle was needed. The following formula is used to determine the  $K_{IC}^S$ .

$$K_{IC}^S = \frac{3SP_{max}}{2bd^2} + \pi\alpha_c F(\alpha) \quad (2)$$

where  $P_{max}$  = Load at maximum (N)  
 $S$  = beam length  
 $b$  = width of beam  
 $d$  = depth of beam  
 $\alpha_c$  = crack length at critical effective.

## 4. RESULTS AND DISCUSSION

### 4.1 Consequence of additives in HPCA deflection-load and CMOD-load curves

As seen in Figure 4 represented the variation of outcome CMOD-P slope equivalent to the

concrete specimens of beam cured for 28 days utilizing ratios of 0.5%, 1%, 1.5%, 2%, and 2.5 % of nA and nS. The HPC with additives P-CMOD curve has a high slope once it reaches the peak (Pmax). A tiny CMOD causes the force value to drop off rapidly. The P-CMOD curve significantly changes when additives are added to concrete at ratios of 2% and 2.5%, particularly when 2.5% of additives are added. The conducted experiment test of beam has elasticity limit still, the curves often grow in the same way at first, but as the curve approaches its peak, a difference begins to become evident. The P-CMOD curve with a reduced additive percentage Once concrete reaches its peak (Pmax), it slopes significantly; at very tiny CMOD values, the force value rapidly drops. There is a noticeable shift in the P-CMOD curve that results from adding chemicals to the concrete at 2% and 2.5%. Since the stages of beginning the reached elastic limit of the concrete. Figure\_ 4 illustrates how the curves of all the samples tend to develop uniformly. The top of the curve for concrete containing additives (2.5%) is higher than that of regular concrete, and variation of slope in HPCA beam curve peak is high. These can readily realize tensile strength of the concrete is higher when additives are used than when they are ignored.

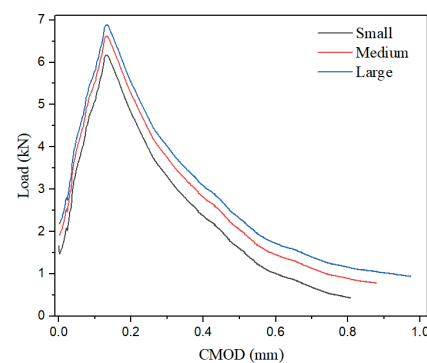


Figure 4. P-CMOD curve of HPCA specimen thickness

The HPCA (2.5%) curve has a lower slope in the period of post-peak than slope of HPCA (0.5%). When comparing similar results in CMOD, the outcome of the load has decreased

growth of slower CMOD as represented in Figure\_4. Specimens with additives continued to have a higher load valuation than specimens with a lower percentage of additives.

In comparison to control samples (0.5%), beam samples with 2.5% additives showed an increase in crack mouth open displacement, or Pmax (CMOD), of 107.14%. The displacement of fractures increased to a maximum of 10% when the CMOD of beam samples with 2.5% additives was achieved maximum compared to sample of control (0.5%). According to the CMOD results, the hardness of concrete is considerably increased by the addition of small amounts of additional particles.

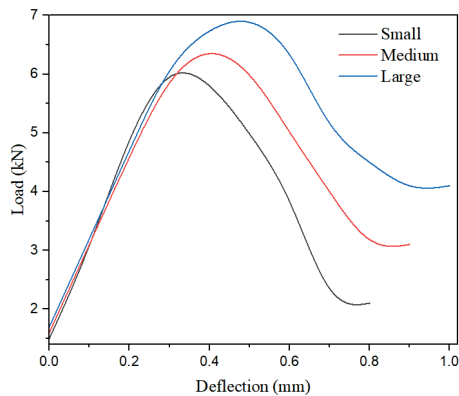


Figure 5. Load deflection curve of HPCA specimen

Figure 5 displays that the HPCA specimen slope of deflection load outcome with different concentration of additives. The load declines more slowly, the slope has been lengthens represented as phase of nonlinear, and slope of P- $\delta$  is thicker for the concrete that uses additives. Based on Figure 5, it is evident that the highest length of position ( $\delta_{max}$ ) test of bending at three points conducted on prepared specimens increases when samples utilizing NS are compared from 0.5% to 1.5% of the control sample (0.5%).

Consider the resulting change in the slope of deflection and load relationship length of the center is depicted in Figure\_5, which also demonstrates how the horizontal axis of the graph and slope of deflection and load under the

area alter in proportion of additives. An area under the P- $\delta$  curve is computed using the integral technique. According to the findings, horizontal axis rose by 7.69%, respectively, at 2.5% additives ratios.

#### 4.2 Influence of additives on the energy of fracture (GF)

The energy of fracture has observed the increases, when the concentration of additives increased from 0.5% to 2.5% is depicted in Figure 6. The fracture energy (GF) produced from the test of bending at three-point is computed using deflection-load slope relationship. The average of six specimens' results is used in the computation. Figure\_6 illustrates that specimens with a larger percentage of additives had fracture energy that increased by 78% when the additives ratio was 2.5%, respectively, when compared to concrete specimens with varied percentages of additives. At 28 days old, the fracture toughness was assessed. Comparing the macro fracture toughness of the additive-added samples (2.5%) to that of the control samples (0.5%), it is shown that the additive-added samples (2.5%) have the best strengthening effect. Adding 2.5% of additives greatly increases the macro fracture toughness. Consequently, it is advised to use 2.5% of additives to enhance fracture characteristics for significant buildings that are vulnerable to frost attack at a relatively young age.

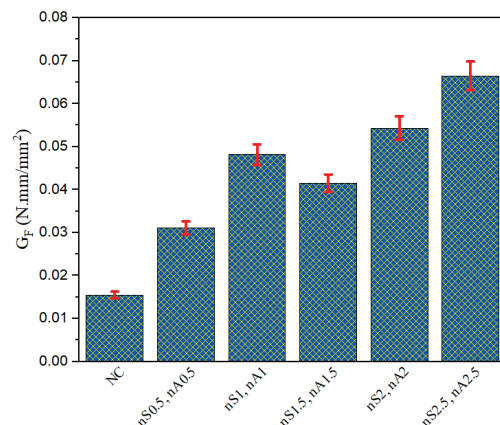


Figure 6. Fracture energy of HPCA specimen.

### 4.3 Mechanical Properties

After the day of 28, the strength of compression was observed for different concentration of additive mixes taken into consideration during the study's initial phase (Figure\_7). The mixtures' 28-day compressive strengths varied from 40 to 53 MPa. As was noted, mixture 2.5% produced the highest compressive strength. Results for compressive strength were often much greater than those for concrete strength at high (i.e., around 53 MPa) or standard concrete (i.e., around 39 MPa).

To the concrete, additives concentration starts with 0% to 2.5% by adding of weight of cement. According to reports, additives enhanced both the concrete's early age strength and compressive strength (AlKhatib et. al., 2020). It was determined that 2.5% of nA and nS concentration provided the best crushing strength (Rakesh et. al., 2021). This study examined an impact of additives as nS and nA on different strength of concretes. nA and nS were substituted in different proportions by cement weight:0.5,1,1.5,2, and 2.5%. The prepared concrete with different concentration of additives (2.5%) has been achieved maximum strength of compression compared to control concrete (0.5%), and the concentration of 0.55 water to cement has been increased by 70%. Compared to lower strength concrete, greater strength concrete was less affected by nS and nA (Mendes et al. 2019) [11].

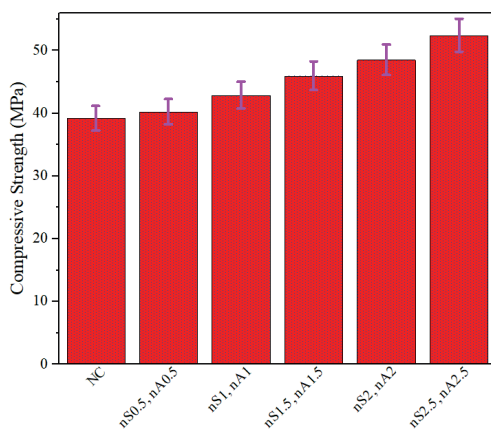


Figure 7. Compressive strength of HPCA specimen

It is evident from the data that 0.5% mixtures were able to reach the minimum compressive strength of 40 MPa. Additionally, mixture 2.5% yielded the best compressive strength of 53 MPa. It's interesting to note that the compressive strength of the combinations slightly worsened when more additives were added.

### 4.5 Splitting Tensile strength

When concretes containing nA and nS were tested in the first stage of the experiment, the strength of tensile splitting concrete was 0.5%, however a greater value was observed for specimens with a nominal weight percentage of 2.5. For the stronger concrete, the additions increased the tensile strength by 2.5%, whereas for the weaker HPCA concrete, the improvement was only 0.5%. The strength improvement for concretes containing higher weight percentages of additives was 2.1% for 0.5wt% and 4.5% for 2.5wt%. 2.1% and 4.5%, respectively, were the increases in tensile strength for tougher concrete (2.5%).

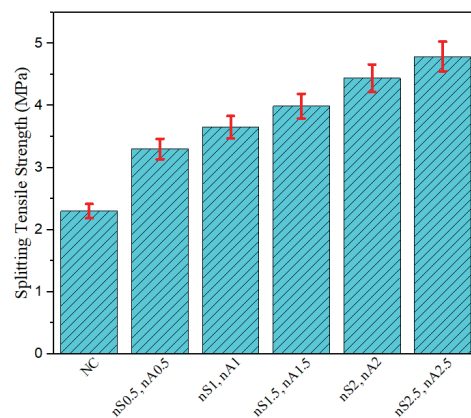


Figure 8. Splitting tensile strength of HPCA specimen

### 4.6 Stress Intensity Factor

With a notch beam in a three-point bend test, the critical stress intensity factor ( $K_{SIC}^S$ ) was experimentally calculated using a closed-loop testing apparatus under the CMOD control. Plots of load-CMOD curves from testing were made. Equation (2) was applied to calculate the

$K_{IC}^S$ . Tests were conducted on concrete specimens at 14 and 56 days. The results are summarized in Figure 8. It demonstrates how the GF and the related tendency of the concrete's  $K_{IC}^S$  are comparable.

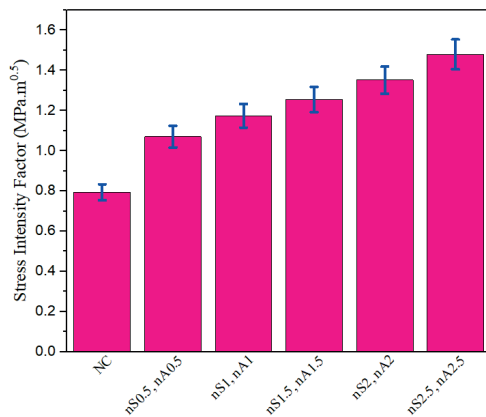


Figure 9. Stress intensity factor of HPCA specimen

The  $K_{IC}^S$  values of HPCA (2.5%) are lower than those of the reference concrete (0.5%) at a young age (14 days), but they rise over 0.5% after 56 days. According to this, the extra pozzolanic reaction of additives with  $Ca(OH)_2$  in concrete is said to become active between the 14 and 56-day mark, increasing the HPCA's  $K_{IC}^S$ . Furthermore, it is shown that for different ages, the concrete with a higher additive level (2.5%) had a lower  $K_{IC}^S$  value than the concrete with a lower additive content (0.5%). Conversely, concrete that has been mixed with finer additives may have higher  $K_{IC}^S$  values. Figure 9 shows that, for a range of ages, an increase in the slag's fineness level causes the  $K_{IC}^S$  value of concrete to rise. Put otherwise, the combination containing finer slag (2.5%) has a higher  $K_{IC}^S$  value (2.5%) compared to the 0.5%  $K_{IC}^S$  value for the same additive replacement ratio (0.5%). Furthermore, for the various ratio of 0.5%, the  $K_{IC}^S$  of 2.5% > 2% > 0.5%. The achievement is attributable to the finer additives (2.5%) particle's larger surface area, which promotes a more active pozzolanic process and elevates strength and fracture toughness.

## 5. CONCLUSION

From the experimental setup of bending test of three point at the different concentration of additives in concrete, the outcomes revealed that the parameters of fracture and properties of HPCA in mode I form were determined. Through experimentation and analysis, the fracture parameters and features of HPCA were established. The outcome of the HPCA has been represented by CMOD-load, deflection and load slope, energy of fracture (GF) and strength of compression. Findings demonstrate that the substantial impact of different concentration of nA and nS on HPC parameters of fracture and features. When it comes to use, the additives ratio of 2.5% is ideal. The enhanced ductility of the HPCA is demonstrated by the fracture energy and distinctive mechanical characteristics.

When 2.5% of HPCA is used, the crack resistance will be stronger than when 0.5% of the control type is used. The mechanical characteristics of HPCA have been reached at 2.5% and 0.5% of additives, respectively, at 53 MPa and 40 MPa. Because of their better filling effect, finer additives (2.5%) have a positive impact on concrete's fracture energy (GF) even at young ages (14 days). The GF value of concrete increases or its fracture toughness is improved with an increase in the fineness level of the added additives. Similar to the fracture energy, the stress intensity factor ( $K_{IC}^S$ ) critical of HPCA (2.5%) has a comparable tendency. Though this study investigates the crack propagation resistance of nano concrete through fracture mechanics, offering valuable insights into its performance. However, several limitations must be acknowledged. Firstly, the experimental scope was restricted to a specific range of nano-materials and concrete compositions. The influence of varying types and concentrations of nano-additives on crack propagation was not exhaustively explored. Additionally, the study focused on static loading conditions; dynamic or cyclic loading scenarios were not considered, which could significantly

impact crack behavior in real-world applications.

Future research should address these limitations by expanding the range of nano-materials and concrete mixtures studied. Investigating the effects of different loading conditions, including dynamic and cyclic loads, would provide a more comprehensive understanding of crack resistance in practical applications. Additionally, incorporating long-term durability studies to assess how environmental factors affect crack propagation could offer deeper insights into the long-term performance of nano concrete. Advanced modeling techniques and larger-scale experiments could further enhance the reliability of predictions and guide the development of more resilient nano concrete formulations. Such efforts will contribute to optimizing nano concrete for diverse structural applications and improving overall construction practices.

#### **DECLARATIONS:**

##### **ETHICS APPROVAL**

No ethics approval is required.

##### **HUMAN AND ANIMAL ETHICS**

Not Applicable.

##### **DECLARATION OF INTERESTS**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

##### **DATA AVAILABILITY STATEMENT**

All the data is collected from the simulation reports of the software and tools used by the authors. Authors are working on implementing the same using real world data with appropriate permissions.

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##### **CONFLICTS OF INTEREST**

The authors declare that we have no conflict of interest

##### **COMPETING INTERESTS**

The authors declare that we have no competing interest.

##### **INFORMED CONSENT**

Not Applicable.

##### **CONSENT FOR PUBLICATION**

Not Applicable

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*Kalpesh Laljibhai Kapadiya* – Research Scholar, Department of Civil Engineering, R. K. University, Rajkot, Gujarat, India, kalpeshlaljibhaikapadiya55@gmail.com

*Калпеш Лалджибхай Кападия* – Научный сотрудник, факультет гражданского строительства, Университет Р.К., Раджкот, Гуджарат, Индия, kalpeshlaljibhaikapadiya55@gmail.com

*Dr. Sanjay Joshi* – 2Professor, Department of Civil Engineering, R. K. University, Rajkot, Gujarat, India, sanjayjoshi9837@gmail.com

*Санджай Джоши* – Профессор, кафедра гражданского строительства, Университет Р. К., Раджкот, Гуджарат, Индия, sanjayjoshi9837@gmail.com

*Dr. Ajaysinh Vaghelas* – Assistant Professor, Department of Civil Engineering, R. K. University, Rajkot, Gujarat, India, ajaysinhvaghelas585@gmail.com

*Аджайсинх Вагелас* – Профессор, кафедра гражданского строительства, Университет Р. К., Раджкот, Гуджарат, Индия, ajaysinhvaghelas585@gmail.com

*Parag Rameshbhai Savsani* – Assistant Professor, Department of Civil Engineering, Dr. Subhash University, Junagadh, Gujarat, India, paragrameshbhaisavsani2@gmail.com

*Параг Рамешбхай Савсани* – Доцент, факультет гражданского строительства, Университет доктора Субхаша, Джунагадх, Гуджарат, Индия, paragrameshbhaisavsani2@gmail.com