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PREFACE

On the occasion of celebrating the 65-year Anniversary of Vinh University, the 2nd International Conference on Advances in Civil Engineering (ICACE-2024) was organized to connect the faculties of the Department of Civil Engineering research professionals, scholars, and scientists from different institutions both in Vietnam and abroad. ICACE-2024 was organized on December 21st, 2024, at Vinh University, Vietnam. This event was a good opportunity to discuss new research findings in the civil engineering field. We believe that those updated studies will contribute to solving the practical problems. The main topics of the conference included Structural and mechanics engineering, Construction and building materials, Smart and sustainable infrastructure, Geotechnical engineering, Hydraulic, pavement, costal and offshore engineering, and Construction engineering and project management. This proceeding includes the full papers selected from the accepted submissions, which were presented at ICACE-2024.

On behalf of the Organizing Committee, we are sincerely thankful for the contribution of two keynote lectures, which are presented by Dr. Samdani Azad (Yonsei University, Korea) and Prof. Tran The Truyen (University of Transportation and Communication, Vietnam). Additionally, a great appreciation is to all authors who submitted papers and presented at the parallel sessions. We also want to give our sincere thanks to companies and Vinh University for their support. Their contributions made the conference a success.

Assoc. Prof. Tran Ngoc Long

*On behalf of the Organizing Committee of ICACE-2024
Dean of Department of Civil Engineering, Vinh University*

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Evaluation of the effect of fiber types on the pullout resistance in concrete under impact loads

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Abstract. This study examines the effects of different diameters of fibers on pullout behavior in ultra-high-performance concrete (UHPC). Three diameters of steel fibers including 0.2, 0.3, and 0.4 mm were selected for this investigation. The pullout tests were carried out under both static (0.0167 mm/s) and impact loads ranging from 340 to 390 mm/s. The results revealed that the diameter of fiber played a critical role in the fiber-matrix interaction, influencing the bond strength and failure mechanisms during impact loading. Furthermore, the results exhibited significant variations in pullout resistance based on fiber diameters, with fibers of larger diameters exhibiting higher pullout resistance due to the increased surface area and higher bond between the fibers and the UHPC matrix. The peak bond strength of matrices with diameters of 0.2, 0.3, and 0.4 mm was 6.86, 10.07, and 15.98 MPa under static loading, increasing to 12.11, 16.89, and 24.94 MPa under impact loading. However, the study also noted that as the fiber diameter increased, the impact load reduced the dynamic increase factors in bond strengths, owing to larger fibers exhibiting a greater tendency for sliding rather than bond failure. The dynamic increase factor (DIF) for the peak bond strength of matrices with fiber diameters of 0.2, 0.3, and 0.4 mm was 1.76, 1.68, and 1.56, respectively, while the corresponding DIF for equivalent bond strength was 1.70, 1.18, and 1.14. These findings offer valuable guidance for optimizing fiber selection and design in UHPC applications exposed to dynamic loading.

Keywords: Pullout resistance, Impact loads, Fiber diameters.

1 Introduction

Ultra-high-performance concrete (UHPC) has become a revolutionary material in contemporary construction due to its outstanding mechanical characteristics including high compressive strength, durability, and superior toughness under static conditions. However, the brittle nature of UHPC under dynamic loads, such as impacts, remains a critical challenge, particularly in applications where resistance to crack propagation and energy absorption are essential. The incorporation of fibers into UHPC has been recognized as a promising strategy to enhance its post-cracking behavior and overall impact resistance [1, 2].

Among the essential parameters affecting the performance of UHPC, the pullout resistance of fibers embedded in matrices is a key parameter influencing their mechanical response, especially under impact loads [2]. The interaction between fibers and matrices governs the stress transfer mechanisms, crack bridging capacity, and energy dissipation under dynamic conditions [3]. Various types of fibers, including steel, synthetic, and hybrid fibers, have been employed in UHPC [4]. Each fiber type offers distinct benefits; for instance, steel fibers provide high tensile strength and stiffness, synthetic fibers enhance flexibility and durability, and hybrid combinations aim to synergize the advantages of different fibers [5]. Furthermore, previous studies have explored the effects of various fiber characteristics, including type, length, and surface treatment, on the pullout behavior in concrete [3, 6]. Fiber diameters

have been identified as a crucial factor influencing the bond strength between fibers and cementitious matrices [7–9]. Qi et al. [8] examined straight fibers (0.2 mm) and hooked-end fibers (0.2 mm and 0.35 mm) under static pullout loads (1 mm/min). Their results indicated that larger fiber diameters enhanced the maximum pullout load, average bond strength, and pullout work, whereas equivalent bond strength decreased owing to increased initial defects in the interfacial transition zone (ITZ). However, there remains limited knowledge regarding the comparative performance of the fiber diameters in enhancing the pullout resistance of UHPC under impact loads.

There is a lack of comprehensive studies on pullout testing under dynamic conditions. Gokoz and Naaman [10] investigated the pullout behavior of smooth steel, glass, and polypropylene fibers in the mortar at velocities of 0.042–3000 mm/s, finding polypropylene sensitive to loading velocity, while smooth steel exhibited no such sensitivity. Banthia and Trottier [11] conducted pullout experiments on deformed steel fibers in both static and dynamic settings, indicating that these fibers demonstrate enhanced pullout resistance under dynamic conditions. Kim et al. [12] studied the impact of loading rates on the pullout response of deformed steel fibers, finding that twisted fibers exhibited greater sensitivity to loading rates compared to end-hooked fibers across matrix strengths of 28 MPa to 83 MPa. Abu-Lebdeh et al. [13] explored the rate-dependent behavior of deformed and smooth steel fibers embedded in matrices with strengths varying from 43 MPa to 196 MPa. The findings revealed that smooth fibers are rate-insensitive, while the rate-dependent pullout response of deformed fibers is governed by embedment length and matrix strength. Although the dynamic pullout behavior of various fibers has been reported, the influence of fiber diameters under impact pullout conditions is still not well understood.

This study aims to evaluate the effect of different fiber diameters on the pullout resistance of UHPC subjected to impact loads. The findings are expected to provide deeper insights into the dynamic pullout behavior of UHPC. The primary objectives of this research were to examine (1) the influence of the fiber diameters on bond strengths of steel fibers embedded in UHPC, and (2) to gain a deeper understanding of the rate sensitivity of fiber pullout resistance with different diameters in UHPC.

2 Experimental procedures

Table 1 details the properties of the compositions and the compressive strength of the matrices at 28 days, whereas Table 2 summarizes the characteristics of steel fibers. The straight smooth fibers were used for diameters of 0.2 mm and 0.3 mm, whereas the hooked-end fiber was employed for the 0.4 mm diameter. In this study, the matrices SP02, SP03, and SP04 are associated with fiber diameters of 0.2 mm, 0.3 mm, and 0.4 mm, respectively. The material composition ratio of the sample mixtures is determined by the proportion of the weight of each material to the weight of cement.

Table 1. Matrix composition and associated compressive strength

Cement	SS	SF	SLP	SP	W/C	Compressive strength (MPa)
1.00	1.10	0.25	0.3	0.07	0.21	187

Table 2. Characteristics of steel fibers

Diameter (mm)	Length (mm)	Density (g/cm ³)	Tensile strength (MPa)	Elastic modulus (GPa)
0.2	19	7.9	2788	200
0.3	30	7.9	2447	200
0.4	30	7.9	2311	200

Portland Cement (PC) served as the primary binder. The grain size of silica sand (SS) used in matrices ranging from 300 to 700 μm . The research employed a water-to-cement ratio (W/C) of 0.21 throughout the experiments. The workability of the mixtures was enhanced by incorporating a polycarboxylate ether superplasticizer with a solid content of 30%. Silica fume (SF) consists of approximately 98.5% SiO_2 , with particle sizes varying between 0.1 and 1.0 μm . As a filler in the matrix, silica powder (SLP) with an average grain size of 10 μm was employed. Its composition includes 98.0% SiO_2 , and its density is 2.6 g/m^3 .

A preliminary dry mixing of sand, silica powder, silica fume, and cement was performed for around 5 minutes. Then, water was incrementally incorporated into the mixture within 1 minute, and mixing continued for roughly 5 minutes. The superplasticizer (SP) was subsequently introduced gradually and stirred for another 5 minutes.

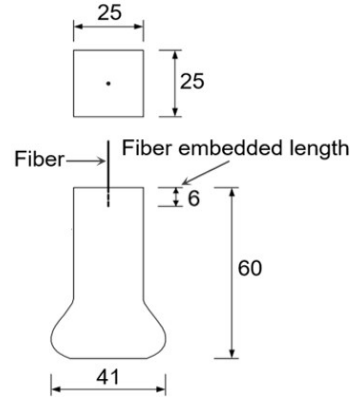
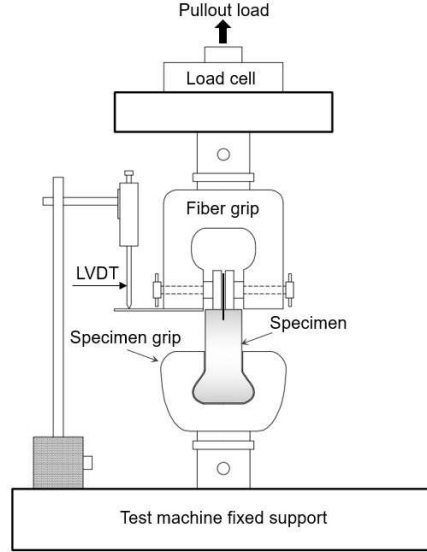
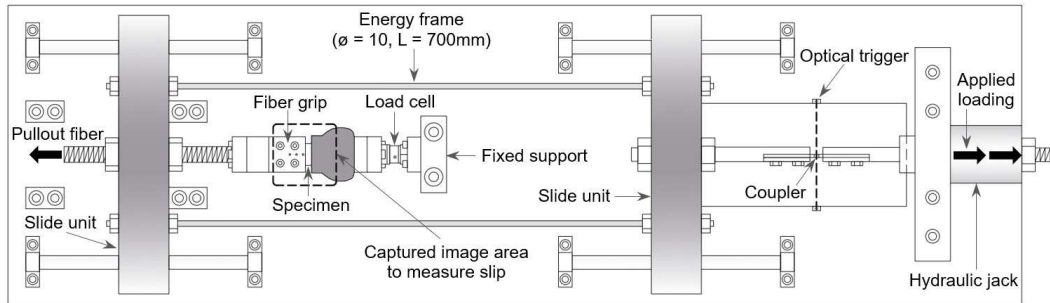


Fig. 1. Pullout specimen (unit: mm)



a) Static pullout experiments



b) Impact pullout experiments

Fig. 2. Pullout test machines [3]

Compression specimens in the form of cubes with precise dimensions of 50 mm × 50 mm × 50 mm were prepared to evaluate the compressive strength of the matrices. A uniform loading speed of 1.0 mm/min was applied throughout compressive tests. The pullout behaviors of steel fibers in matrices were investigated using bell-shaped pullout specimens, as demonstrated in Fig. 1. In preparation for casting, a fiber was positioned in the molds with an embedded length of 6 mm. After the casting process, all specimens were covered with plastic sheets and kept at room temperature for 48 hours. Following demolding, the samples were cured in water curing at 90 ± 2 °C for 3 days and tested after 28 days under dry conditions [3]. Fig. 2 illustrates that two types of pullout test machines were employed to examine the pullout responses of fibers embedded in matrices [3]. Pullout loads were carried out at pullout rates varying between static (0.0167 mm/s) and impact loads ranging from 340 to 390 mm/s.

3 Result and Discussion

The pullout resistance was quantified by calculating the equivalent bond strength (τ_{eq}) and the peak bond strength (τ_{peak}), as indicated in Eqs. (1) and (2) [3, 14–16].

$$\tau_{eq} = \frac{2P_E}{\pi d_f L_{em}^2}, \quad (1)$$

$$\tau_{peak} = \frac{P_{Peak}}{\pi d_f L_{em}}, \quad (2)$$

where P_E refers to the pullout energy, P_{Peak} corresponds to the maximum pullout load, d_f denotes the diameter of the fiber, and L_{em} represents the embedded length of fibers.

Table 3 summarizes the pullout resistances of fibers in all matrices, which were determined using Eqs. (1) and (2). P_{Peak} and P_E for all matrices exhibited a general increase with rising fiber pullout rates. Besides, as the fiber diameter increased, the interfacial bond strengths of matrices increased under both static and dynamic loading conditions. At static loading, the P_{Peak} values for SP02, SP03, and SP04 were 6.86 MPa, 10.07 MPa, and 15.98 MPa, respectively, while their corresponding P_E values were 7.29 MPa, 12.16 MPa, and 16.56 MPa, as illustrated in Fig. 3. Under impact loading, the P_{Peak} values for SP02, SP03, and SP04 increased to 12.11 MPa, 16.89 MPa, and 24.94 MPa, respectively, while their P_E values were 12.42 MPa, 14.29 MPa, and 18.91 MPa, respectively, as shown in Fig. 3.

Table 3. Pullout resistance of steel fibers in matrices

Matrix	Pullout rate	Peak pullout load	Peak bond strength		Equivalent bond strength	
	mm/s	N	MPa	DIF	MPa	DIF
SP02	0.0167	25.87	6.86	1.00	7.29	1.00
	342	45.66	12.11	1.76	12.42	1.70
SP03	0.0167	56.92	10.07	1.00	12.16	1.00
	381	95.53	16.89	1.68	14.29	1.18
SP04	0.0167	120.45	15.98	1.00	16.56	1.00
	387	188.02	24.94	1.56	18.91	1.14

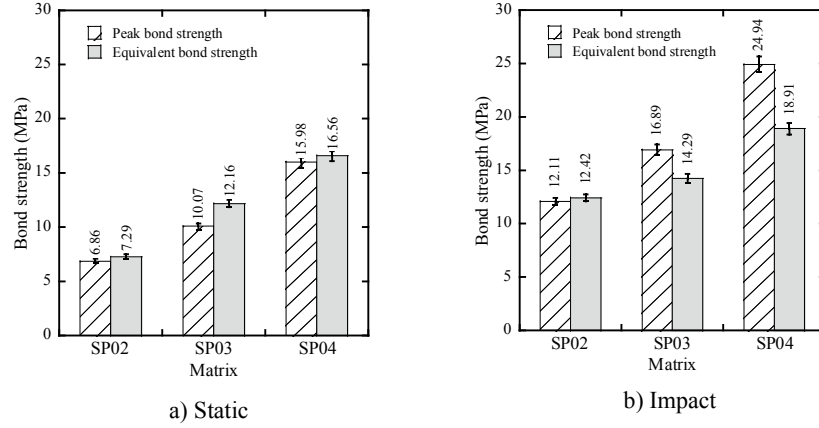


Fig. 3. Bond strength of matrices under static and impact pullout loads

In addition, Fig. 4 provides a comparison of the effects of the fiber pullout rates on the pull-out load versus slip curves of matrices. An increase in fiber size results in a higher maximum pull-out load, which aligns with findings from the literature [8]. Moreover, the rate sensitivities of matrices were found to be notably enhanced at high pullout rates. The greater pullout resistances at high pullout rates could be explained by the effects of the incubation time during the fiber pullout tests [3, 17, 18]. At lower pullout rates, the propagating cracks would have adequate time to identify the weakest path in ITZs between fiber and matrix as the pullout load was applied. In contrast, at higher pullout rates, the cracks form quickly, leaving insufficient time to find the weakest path, which results in the development of multiple microcracks in the ITZ [3, 18, 19].

However, at the impact pullout rates, SP04 matrices exhibited a lower dynamic increase factor (DIF) for both τ_{peak} (1.56) and τ_{eq} (1.14) compared to SP03 and SP02 matrices, which had values of 1.68 for τ_{peak} , and 1.18 for τ_{eq} corresponding to SP03 matrix, and had values of 1.76 for τ_{peak} , and 1.70 for τ_{eq} corresponding to SP02 matrix, as provided in Table 3. This occurred despite the general trend of increasing DIFs for SP04 matrices with higher pullout rates. This may suggest that larger fibers provide more contact area with the matrix, which generally enhances frictional resistance. However, at high pullout rates, the frictional resistance could diminish more significantly for larger fibers due to the increased tendency for sliding rather than fiber-matrix bond failure.

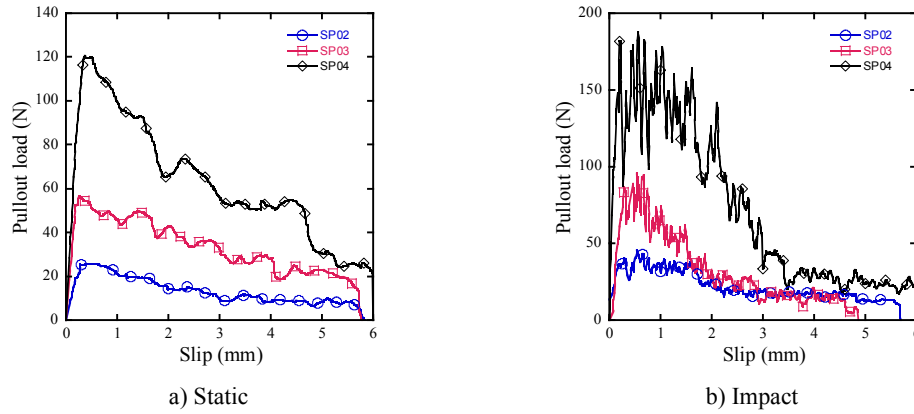


Fig. 4. Pullout load versus slip curves of matrices under static and impact loads.

4 Conclusions

This study explores the role of fiber diameter variations in influencing the pullout behavior of UHPC. Steel fibers with diameters of 0.2 mm, 0.3 mm, and 0.4 mm were chosen for this investigation. Pullout tests were conducted under static conditions (0.0167 mm/s) as well as impact loads within the range of 340 to 390 mm/s. The findings of this study can be summarized as follows:

- As the fiber diameter increases, the interfacial bond strengths of the matrices are enhanced under both static and dynamic loading conditions. The peak bond strength of matrices with diameters of 0.2, 0.3, and 0.4 mm at static loads was 6.86, 10.07, and 15.98 MPa, respectively, while under impact loading, these values increased to 12.11, 16.89, and 24.94 MPa, respectively. This suggests that larger fibers contribute to stronger interfacial bonds in cement composites.
- Pullout resistance of steel fibers embedded in UHPC increased with rising fiber pullout rates. Higher pullout rates increase rate sensitivity, with cracks forming rapidly and leading to multiple microcracks in the ITZ. This behavior is influenced by the limited time for crack propagation at higher rates.
- Fibers with larger diameters are less sensitive to pullout rates compared to smaller ones, suggesting that the increased contact area with the matrix enhances frictional resistance. However, at higher pullout rates, frictional resistance may decline more notably for larger fibers due to a higher tendency for sliding rather than fiber-matrix bond failure. The dynamic increase factor (DIF) for peak bond strength of matrices using fiber diameters of 0.2, 0.3, and 0.4 mm was 1.76, 1.68, and 1.56, respectively, while the DIF for equivalent bond strength of the matrices was 1.70, 1.18, and 1.14, respectively.

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