THE OPTIMIZED DESIGN OF DOG-BONES FOR TENSILE TEST OF ULTRA-HIGH PERFORMANCE CONCRETE

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Abstract

Sustained post-cracking tensile resistance is a fundamental mechanical property of ultra-high performance concrete (UHPC). The uniaxial tensile test is a very sensitive and difficult test to conduct. The research can improve the success rate of direct tensile test for UHPC by designing special dog-bone specimens. Then dog-bone specimens have unique advantages. When the cross-sectional area near the ends of the specimens is increased, the boundary stresses will be reduced and bond failure is generally avoided. The failure should occur in the prismatic part of the specimen where, in theory, the shape effects are absent. The tensile stress in the effective test area is the key to the success of the uniaxial direct tension test. So, the effects of a set of non-dimensional geometric parameters on the stress distribution were numerically investigated. A total of 125 dog-bones specimens were analyzed using the non-dimensional parameters, and an equation was proposed to assess the tensile stress in effective test area. Based on the stress distribution in the effective test area, an optimized design is proposed for the dog-bone shape to improve the success rate of the uniaxial tensile test. Five dog-bone specimens were tested for verification of the optimized dog-bone shape that can.

Résumé

Le maintien d'une résistance en traction post-fissuration est une propriété mécanique fondamentale des bétons fibres à ultra-hautes performances (BFUP). L'essai de traction uni-axiale est un essai très sensible et délicat de mise en œuvre. La présente recherche est susceptible d'améliorer le taux de succès de l'essai de traction directe sur BFUP en concevant des éprouvettes en diabolo spécifiques. En effet les éprouvettes en diabolo ont des avantages propres. Avec l'augmentation de l'aire de leur section aux extrémités, les contraintes aux limites sont réduites et la rupture d'adhérence est généralement évitée. La rupture doit se produire dans la partie prismatique de l'éprouvette où les effets géométriques sont en théorie inexistants. La contrainte de traction dans la zone de test effective gouverne le succès de l'essai de traction directe uni-axiale. En conséquence, l'influence d'un jeu de paramètres géométriques adimensionnels sur la répartition des contraintes a été étudiée numériquement. Au total 125 corps d'épreuve en diabolo ont été analysés grâce aux paramètres adimensionnels, et une équation a été proposée pour évaluer la contrainte de traction dans la zone de test effective. Sur la base de la répartition des contraintes dans cette zone, une forme optimisée a été proposée pour améliorer les chances de succès de l'essai de traction uni-axiale. Cinq éprouvettes ont été testées pour confirmer cette optimisation.

1. INTRODUCTION

Testing for tensile strength of concrete mainly involves three different approaches: uniaxial testing, flexural testing (modulus of rupture), and splitting tests. While flexural and split tensile tests are indirect measures, the uniaxial test directly measures the material's tensile behaviour. However, direct tensile tests are challenging to conduct. Difficulties in obtaining evenly distributed stresses throughout the cross section and controlling a stable load versus displacement/crack opening response has limited the number of such tests on cementitious materials and composites. Since the traditional concrete tensile strength is only 1~2 MPa, the designers generally do not consider the concrete tensile strength in their design calculations for strength limit states. So, uniaxial tensile tests are rarely used. At the same time, uniaxial tensile strength testing has not benefitted from in-depth research. In UHPC applications, the tensile strength is generally greater than 7 MPa, thus playing a more significant role in strength calculations. Therefore, the tensile strength of UHPC is a very important technical indicator, and a study on the technology of uniaxial tensile strength testing is warranted.

With the development of UHPC materials and engineering research, many UHPC uniaxial tensile tests were conducted. Then dog-bones specimens have unique advantages. When the cross-section towards the ends of the specimens is increased, the boundary stresses will be reduced and the bond failure is generally avoided. The failure should occur in the prismatic part of the specimen where, in theory, the shape effects are absent. Due to the typology of the transition region, specimens can be divided into the arc-dog-bone, the trapezoid-dog-bone and the multiple-dog-bone specimens. The arc-dog-bone of the stress uniformity is better than others. Therefore, this paper will study the size of the arc-dog-bone specimens in uniaxial tensile test success rate. Numerous researches (Hassan [1], Naaman [2, 4], Kamal [3], Sujiravorakul [5] etc.) chose arc-dog-bone specimen for their UHPC tensile strength testing [1-14]. However, they were mainly focused on UHPC tensile behaviour, and not on improving the success rate of such tests. While AFGC-SETRA [15] and JSCE [16] both provide recommendations on how to perform uniaxial tensile tests on UHPC materials, there are currently no testing standards available that define the test conditions, specimen geometry, and analytical procedures necessary to fully characterize the tensile properties of strain-hardening cementitious materials. Therefore, this paper will study the size of the arc-dog-bone specimens in uniaxial tensile test success rate.

Uniaxial tensile tests could directly reflect UHPC tensile behaviour at all three stages of the tensile process (elastic, pseudo strain hardening, and softening). However, direct tensile tests are challenging to perform. Difficulties in obtaining evenly distributed stresses throughout the cross section and controlling a stable load versus displacement/crack opening response have limited such direct tensile tests on cementitious materials and composites. Based on preliminary finite element analyses, this paper argues that is in the elastic stage of the uniaxial tensile test. It is further suggested that the stress in the transition regions should not be greater than the stress in the prismatic regions (in the elastic stage) to avoid failure. FEA was performed to evaluate the effects of geometric parameters on the stresses in the dog-bone.

2. FINITE ELEMENT MODEL OF ARC-DOG-BONE SPECIMENS

The numerical analysis in the stress distribution of the dog-bones specimens under uniaxial tension testing was conducted by using the general finite element analysis software ABAQUS. The arc-dog-bone specimens is shown in Figure 1. The finite element model of arc-dog-bone is shown in Figure 2a. The arc-dog-bone specimens were divided into five elements in the thickness direction, as shown in Figure 2c, while the anchorage region was divided into three elements the transition region was divided into six elements and the prismatic part was divided into twenty elements, as shown in Figure 2b. The mesh could achieve accurate results with appropriate computational time and reliable accuracy by using FEA validation. The elastic modulus is 48.9 GPa. Loading and boundary conditions choose unit negative pressure. The stress distribution in the trapezoid-dog-bone is shown in Fig. 2d.

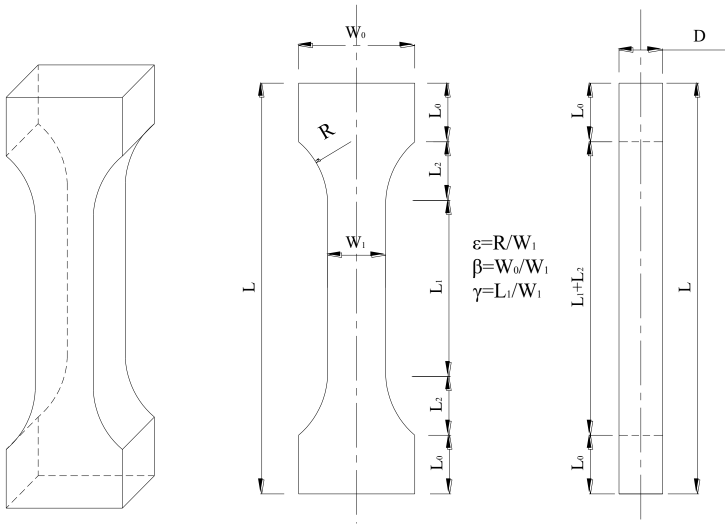
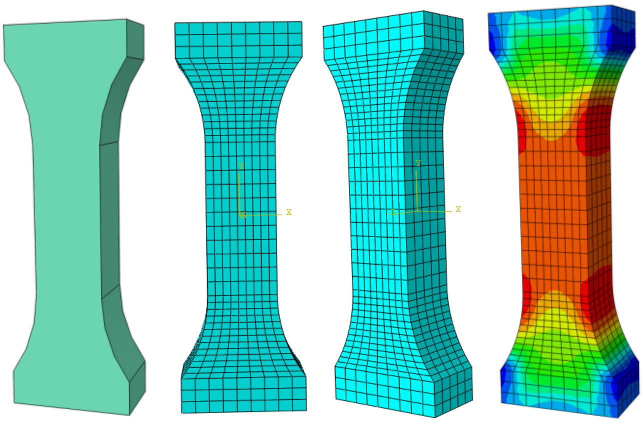


Figure 1: the arc-dog-bone specimens



(a) model (b) meshes (c) meshes (d) stress distribution

Figure 2: the finite element meshes of the arc-dog-bone

3. PARAMETER ANALYSIS

3.1 Parameter design of arc-dog-bone specimens

The non-dimension parameters studied in the paper were β, γ and ε. The numerical analysis was processed with mass geometric parameters in the practical ranges in Table 1. The practical ranges were referenced to above analysis. In order to focus on analysis of main parameters, this paper defines the rest of the parameters as following.

W1 = 50 mm the prismatic part width is 50 mm
D = 50 mm the specimen thickness is 50 mm
S = 1 N/mm² uniaxial tensile stress is 1 N/mm²
L_0 = 25 mm the anchor length is 25 mm

All 125 joints were analyzed in the non-dimension parameter about σ_v/σ_m. The identical element type, mesh size and material modelling of steel tubes used in the validation study were also employed in the parametric study.

Table 1: Non-dimension parameters selected within the practical ranges of the arc-dog-bone specimens

Parameters	value				
ε	0.5	1.0	1.5	2.0	2.5
β	1.4	1.8	2.2	2.6	3.0
γ	1.0	1.3	1.6	1.9	2.2

3.2 Parameter analysis results of arc-dog-bone specimens

The non-dimension parameters studied in the paper were β, γ and ε of the arc-dog-bone specimens. The parameter β considers the effect of the size of anchor part on stress distribution under uniaxial tensile test in elastic stage. The parameters γ considers the effect of the length and width of prismatic part on stress distribution under uniaxial tensile test in elastic stage. And the parameter ε considers the effect of the radius of transition part on stress distribution under uniaxial tensile test in elastic stage.

After the finite element model has been verified with the influences of the geometry parameters on stress distribution under uniaxial tensile test in elastic stage. The σ_v/σ_m of 125 FE models are determined using the current proposed stress distribution parametric influence.

As β increases, the σ_v/σ_m is decreased. As shown in Figure 3, we can see that the increase in the size of anchor parts leads to the decrease of σ_v/σ_m, so the increase in the size of anchor aggravate the uneven distribution of stress. However, when the cross-sectional area near the ends of the specimens is decreased, the boundary stresses will be increased and bond failure is difficult to avoid. In conclusion, the paper suggests that β should be chosen as moderate as possible.

As shown in Figure 4, we can see that the γ is not significant impact for stress distribution of the arc-dog-bone specimens under uniaxial tensile test in elastic stage. However, when the length-width ratio is less than 2, it can't uneven distribution stress in prismatic segment according to the finite element analysis. In conclusion, the paper suggests that the γ whose value is 2.

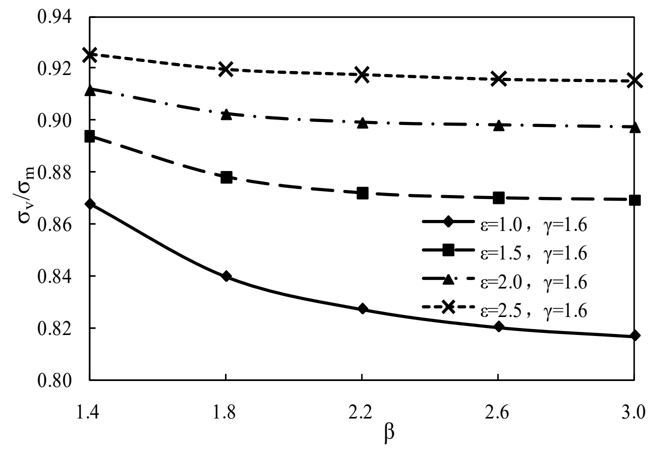


Figure 3: Curves of σ_v/σ_m–β

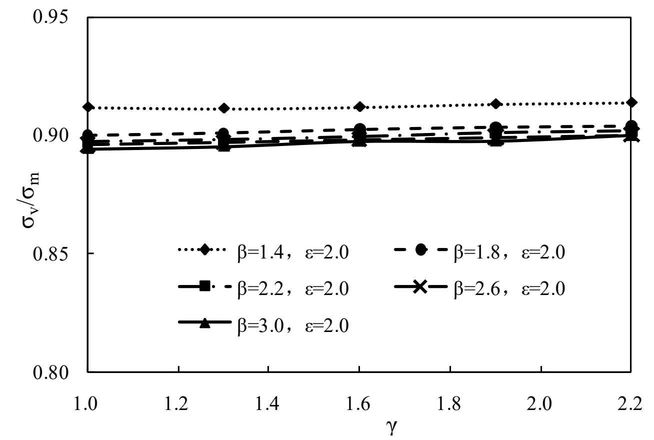


Figure 4: Curves of σ_v/σ_m–γ

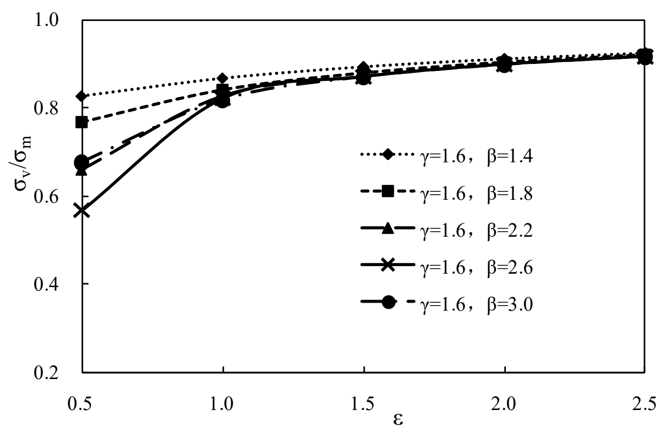


Figure 5: Curves of σ_v/σ_m–ε

As ε increases, the σ_v/σ_m is increased, so the increase in the radius of transition parts can improve the uniform distribution of stress. However, the trend declined when ε more than 1.5. In conclusion, the paper suggests that the ε whose value is about 1.5.

4. VERIFICATION TESTING

In conclusion, the paper suggests that ε whose value is about 1.5, γ whose value is 2 and β should be chosen as moderate as possible. Comprehensive analysis, this paper recommend to $\varepsilon = 1.4$, $\beta = 2$, and the $\gamma = 2$ of the arc-dog-bone specimen.

Five arc-dog-bone specimens were designed and built-up to verify the effectiveness of the design. The selected geometrical properties of the dog-bone specimens are this paper recommend. As shown in Figure 6, all specimens showed failure within the prismatic segment. The success rate was 100 %. This design significantly improves the potential for success in uniaxial tensile tests.

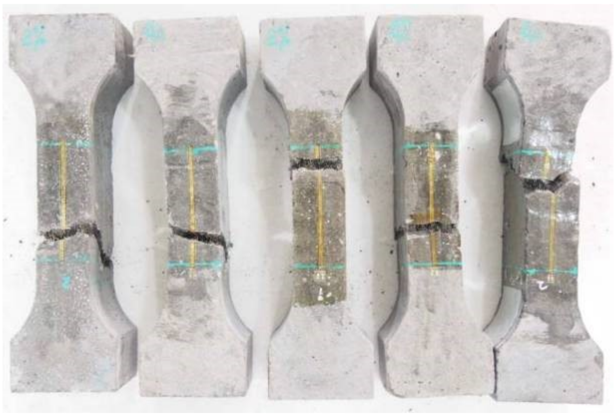


Figure 6: Verification test results.

5. CONCLUSIONS

Experimental and numerical investigations on stress distribution in the elastic stage of the uniaxial tensile test were conducted in this study, analysing the stress distribution which could improve the success rate of uniaxial tensile test. According to the experimental and numerical investigations, main conclusions are listed as follows:

- The paper suggests that β should be chosen as moderate as possible.
- The paper suggests that the γ value should be 2.
- The paper suggests that the ε whose value is about 1.5.
- The paper recommends to design the arc-dogbone specimen that can improve the potential for success in uniaxial tensile tests.

Nomenclature

FEA is finite element analysis.

UHPC is ultra-high performance concrete mixtures

L_1 is the prismatic part length

L_2 is the transition part length

L_0 is the anchor part length

L is the specimen length
W_1 is the prismatic part width
W_0 is the specimen width
D is the specimen thickness
θ is the transition part incline angle of the trapezoid-dog-bone specimens
R is the transition radius of curvature of the arc-dog-bone specimens
σ_v is the stress value of the prismatic part
σ_m is the maximum stress value of the transition region in the elastic stage.
β is the width anchor-width prismatic ratio
γ is the length-width ratio of prismatic
ε is the radius transition-width prismatic ratio

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