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**The Impact of the Elastic Modulus of Shell Structures on the Stress
Field in Concrete**

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Abstract:

This study investigates the response ability of external additives in shell structures to matrix cracks. Starting with the analysis of the stress field around the carrier, we establish a strength model for shell structures. Based on an empirical formula for the elastic modulus fitted from experimental data, we analyze the stress coefficients of matrices with different elastic moduli for the shell additives. The findings reveal that an increase in the elastic modulus of the shell leads to a greater maximum stress concentration coefficient in the shell.

Concrete is one of the most widely used engineering materials globally and is expected to remain irreplaceable in the foreseeable future. However, it is inherently brittle [1], exhibiting poor volume stability under changes in temperature and humidity, which makes it prone to cracking. Cracked concrete has lower protective performance, as external intrusive ions can quickly penetrate the material through the cracks. Research indicates that the ion transport rate in cracked regions of concrete increases exponentially, particularly when the cracks reach a certain width, at which point the ion transport rate can be comparable to that in water. Infiltrated ions can induce new types of deterioration, such as physical erosion caused by salt crystallization and chemical erosion from highly expansive minerals,

leading to further damage and new cracks in the concrete [2]. The coupled deterioration significantly accelerates the degradation of material performance, ultimately resulting in a reduction in structural functionality and failure. Therefore, timely and effective repair and maintenance have become crucial for ensuring the long service life of engineering structures. Conventional repair methods primarily rely on manual inspection and the application of synthetic repair agents. In contrast to lower inspection efficiency and short-term maintenance capabilities, along with potential environmental issues, self-healing technologies capable of autonomous diagnosis and proactive repair have emerged as a significant research direction in modern engineering materials.

Core-shell repair agents are a type of granular functional component, and their functional expressions can be controlled by altering the material parameters of the shell to meet various engineering needs. Thus, core-shell particles in concrete cannot be simplified to the problem of circular holes in an infinite plate; when constructing a physical model, the influence of the carrier must be considered. In a two-dimensional plane, the carrier can be viewed as an annulus, and the stress distribution in the carrier and its surrounding area relates to the stress distribution problem of an infinite plate with non-uniform material at the circumferences of the holes.

The equilibrium equations for the plane stress problem of the annulus and its surrounding area in polar coordinates (Equations 1 and 2):

$$\frac{\partial \sigma_r}{\partial r} + \frac{1}{r} \frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \quad (1)$$

$$\frac{\partial \sigma_{r\theta}}{\partial \theta} + \frac{1}{r} \frac{\partial \sigma_\theta}{\partial \theta} + \frac{2}{r} \sigma_{r\theta} = 0 \quad (2)$$

In the equations: σ_r : Radial stress; σ_θ : Circumferential stress; $\sigma_{r\theta}$: Shear stress.

The equilibrium equations for the plane stress problem indicate that the "core" of the repair agent induces stress concentration between the carrier and the matrix. If the carrier exhibits good responsiveness, then the stresses in the carrier and the matrix should have a well-coordinated relationship. Assuming that the Poisson's ratio for both the carrier and the concrete matrix is 0.2, with an inner diameter of the core-shell repair agent particle set at 1.0 mm and an outer diameter of 2.0 mm, we let the elastic modulus of the shell vary between 10/15/20/25/30/35/40/45GPa, while the elastic modulus of the concrete matrix is taken to be 30 Gpa.

The stress concentration coefficients for the carrier and matrix are calculated based on the equilibrium equations of plane stress shown in Fig.1. Under external loading, the trend of stress concentration coefficients in the various cases of the shell remains consistent, gradually decreasing with increasing distance from the center of the circular hole. The maximum stress concentration coefficients for both the shell and matrix occur near the point of minimum distance to the center of the hole. The peak stress concentration coefficient in the shell is located on its inner side, while the maximum stress concentration coefficient in the concrete matrix is situated at the interface where the shell meets the matrix. Notably, the stress concentration coefficients at the shell-matrix interface do not exhibit continuity.

The variations in the elastic modulus of both the matrix and shell result in significant changes in the internal stress concentration coefficients. As the elastic modulus of the shell increases, the stress concentration coefficient also rises, whereas the stress concentration coefficient within the concrete matrix decreases. This indicates an inverse relationship between the stress concentration coefficients of the shell and the concrete matrix. This behavior is attributed to the fact that the cavity of the annular hole lacks load-bearing capacity, causing stress to be redistributed to the shell and surrounding matrix. When the shell bears a greater portion of the stress, the corresponding stress assigned to the matrix is reduced.

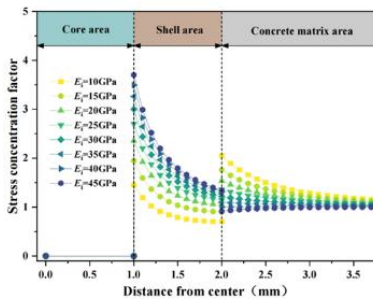


Fig. 1. The Impact of Elastic Modulus on Stress Coefficient

When the shell's elastic modulus is set at 15 GPa, the maximum stress concentration coefficients of the shell and matrix are nearly the same. If both materials have identical tensile strengths, they are likely to crack

simultaneously under external stress. If the maximum stress concentration coefficient of the matrix does not exceed 1.5, for a matrix with an elastic modulus of 30 GPa, the carrier with an inner diameter of 1.0 mm and an outer diameter of 2.0 mm should have a shell elastic modulus of no less than 20 GPa. When both elastic moduli are at 20 GPa, the situation can be treated as a circular hole in an infinitely large plate, where the maximum stress concentration coefficient along the hole wall is 3.

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

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Discussion on greening transportation roads by using non-metallic fiber asphalt concrete

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Abstract:

Asphalt pavement has been widely used in road engineering, but the production of traditional asphalt concrete requires a large amount of high-quality minerals, asphalt and fuel. Therefore, the green transformation of traditional asphalt concrete has become a top priority. In order to promote the sustainable development of asphalt pavement and social energy, environment and ecology, this paper improves asphalt concrete by adding green non-metallic fibers, and discusses the ecological, high-performance and functional development of road asphalt concrete.