Study on Influencing Factors of Leakage of Epoxy Resin Grouting

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Abstract. As a kind of grouting material, epoxy resin is often used to repair cracks in concrete structures and as grouting filling for reserved joints in prefabricated buildings. However, in engineering applications, gaps can be found between water-stop tape and concrete. Due to the low viscosity of epoxy resin, leaks easily occur during the grouting process. In order to study the influencing factors of leakage, numerical simulations were used to determine the leakage rate of epoxy resin between the size of the leakage aperture, the grouting pressure, and the viscosity of epoxy resin. The change of pressure at the position of the leak under different conditions was also obtained. The results showed that under different viscosities, the leakage velocity exhibits different laws to the area of the hole and the grouting pressure.

1. Introduction

It is necessary to grout the cracks in cement concrete or the reserved cracks in assembled structures. The grouting of cracks plays a key role in the overall mechanical properties of structures and provides them with waterproofing and impermeable ability [1-3]. However, in the joint pouring process, there are some issues such as the intense paste of water-stop adhesive strips, large deformation of transverse joints, and the bursting of water-stop adhesive strip by slurry pressure. Moreover, the viscosity of epoxy resin is too thin, which causes a large amount of slurry to flow away from the gap of the water-stop adhesive strip. This even leads to the failure to fill the joint within the specified time, affecting the construction quality.

Epoxy resin is more widely used in crack repair and as a grouting filler for prefabricated structural joints in the construction industry due to its low viscosity, good fluidity, strong adhesion after hardening, shrinkage reduction, and good stability. Yuan studied the effects of several inorganic fillers on low-viscosity epoxy resin properties and concluded that the resin's mechanical properties are optimal when zinc oxide is used as a filler, and when the filling amount is 60% of the total mass of the resin [4]. Huang et al. conducted an experimental study on the application of epoxy resin in a prefabricated subway station. They concluded the rationality of epoxy resin as prefabricated subway station seam grouting, and determined that the compressive strength and elastic modulus were close to the maximum when the proportion of epoxy resin and quartz powder was 1:0.5 to 1:0.8 [5]. There are few studies on the leakage of epoxy resin grouting. Wang et al. studied the influence of the oil and gas pipeline pressure and flow speed on the leakage amount, and concluded that the larger the initial pressure and aperture, the faster the leakage rate of the pipeline, with the leakage amount being proportional to the change of pressure.
Since research objects are generally oil, gas, water, etc., a discussion of viscosity has not been introduced.

Currently, there is less research of the occurrence of leakages of epoxy resin grouting. Therefore, through using ANSYS Fluent software for simulation to study the influencing factors of epoxy resin leakage rate, this article aimed to find the viscosity of epoxy resin, as well as the influence of leakage aperture size and grouting pressure on the leakage rate, in order to reduce the risk of leakage.

2. The Numerical Simulation Method

The CFD software ANSYS Fluent was used for numerical simulation analysis, as some researchers have studied pipeline leaks in different areas by CFD simulation [9-11].

The epoxy resin leakage pipe model was built using Geometry in ANSYS Workbench. Five pipe models of 1 m in length and 2.1 cm in diameter were created. The pipe simulates the channel of grouting, and the hole simulates the gap that may exist during grouting. Holes with diameters of 1–5 mm were left at 20 cm on one side of the pipe. Figure 1 shows the circular pipe model with a hole diameter of 3 mm.

According to the Reynolds number formula, the flow in a circular pipe was judged to be laminar, so the laminar flow model was selected. The pressure inlet boundary condition was adopted at the right side of the pipe mouth, and the pressure range was 0.1–0.5 MPa. The left pipe mouth was set as the wall boundary, and the hole was set as the pressure outlet. The surface boundary condition was the non-slip solid wall boundary condition. The grid was divided by MESH, and the element type was tetrahedral. Epoxy resin is an incompressible viscous fluid, and its mass equation and momentum equation are expressed as follows [12]:

$$\frac{\partial p}{\partial t} + \frac{\partial (\rho u_x)}{\partial x} + \frac{\partial (\rho u_y)}{\partial y} + \frac{\partial (\rho u_z)}{\partial z} = 0$$  \hspace{1cm} (1)

$$\frac{\partial (\rho u_x)}{\partial t} + \nabla \cdot (\rho u_x \vec{u}) = - \frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x$$  \hspace{1cm} (2)

$$\frac{\partial (\rho u_y)}{\partial t} + \nabla \cdot (\rho u_y \vec{u}) = - \frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y$$  \hspace{1cm} (3)

$$\frac{\partial (\rho u_z)}{\partial t} + \nabla \cdot (\rho u_z \vec{u}) = - \frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z$$  \hspace{1cm} (4)
Where $\mu_x$, $\mu_y$, and $\mu_z$ are the velocity vectors in X, Y, and Z, respectively (m/s); $t$ is time (s); $\rho$ is the density (kg/m$^3$); $p$ is the pressure on the fluid microelement body (Pa); $\tau_{xx}$, $\tau_{xy}$, $\tau_{xz}$, etc., are the components of the adhesive stress $\tau$ acting on the surface of the microelement due to molecular viscosity (Pa); $f_x$, $f_y$, and $f_z$ are the unit mass forces in three directions (m/s$^2$).

3. Results

3.1. Pressure Variation in the Pipe with Different Apertures

Figure 2 shows the pressure distribution in pipelines with different apertures when the inlet pressure was 0.3 MPa, and the viscosity was 25 Pa.s. The experimental design pressure inlet range was 0.1–0.5 MPa. Figure 6 only took the pressure at 0.3 MPa as an example. The viscosity was set to 25 Pa. s, close to the viscosity of epoxy resin at room temperature (25 °C). As shown in Figure 2, the larger the hole size, the larger the pressure drop of the pipe. By analyzing the pressure at the point marked in Figure 6, it can be concluded that the pressure around the small hole decreased linearly with the increase in the small hole area.
Figure 2. Pressure variation in a circular pipe with different leakage apertures. (a) A hole diameter of 1 mm; (b) a hole diameter of 2 mm; (c) a hole diameter of 3 mm; (d) a hole diameter of 4 mm; (e) a hole diameter of 5 mm.
3.2. Pressure Change in a Pipe with Different Viscosities

Figure 3 shows the pressure distribution in the pipeline under different viscosities when the inlet pressure was 0.3 MPa and the hole diameter was 3 mm. The diameter of the small hole on the sidewall of the circular pipe was 1–5 mm, and the inlet pressure was 0.1–0.5 MPa. Figure 7 shows a small hole diameter of 3 mm and an inlet pressure of 0.3 MPa as examples. The viscosity was 0.25, 1, 4, 16, 32, or 128 Pa.s. As shown in Figure 7, the higher the viscosity of the epoxy resin in the pipeline, the greater the pressure drop in said pipeline. The reason is that viscous fluid generates internal friction resistance between fluid particles and consumes part of the mechanical energy, which is converted into heat energy and dissipated. It can also be seen from Figure 3 that when the viscosity of the epoxy resin was low, the pressure in the pipeline changed significantly. Still, when the viscosity was greater than 10 Pa.s, the pressure in the pipeline did not change significantly. The reason is that when the viscosity was lower than 10 Pa.s, the epoxy resin had strong fluidity. The change of viscosity between regions led to drastic changes in the fluidity. When the viscosity was greater than 10 Pa.s, the fluidity of epoxy resin became so slow that the range of change was not obvious.
Pressure is 0.233 MPa

Pressure is 0.207 MPa

Pressure is 0.205 MPa
Figure 3. The pressure in the pipe changed with different viscosity. (a) Viscosity of 0.25 Pa. s; (b) viscosity of 1 Pa. s; (c) viscosity of 4 Pa. s; (d) viscosity of 16 Pa. s; (e) viscosity of 32 Pa. s; (f) viscosity of 128 Pa. s.

Table 1 shows a flow diagram of a 2 mm leaking pipe at different pressures and viscosities; In practical engineering, the viscosity required for epoxy resin grouting is usually lower than 0.03 Pa. s, but it can be seen from the table that the flow rate did not change significantly with an increase of viscosity between 0.001 and 1 Pa.s. Therefore, to reduce the cost of grouting, adding quartz powder can reduce the amount of epoxy resin. It is best to keep the viscosity of epoxy resin below 1 Pa.s.

Table 1. Leakage velocity meter with a diameter of 2 mm.

| Viscosity (Pa. s) | Flow at the pressure of 0.1MPa (g/s) | Flow at the pressure of 0.2MPa (g/s) | Flow at the pressure of 0.3MPa (g/s) | Flow at the pressure of 0.4MPa (g/s) | Flow at the pressure of 0.5MPa (g/s) |
|-------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| 0.01              | 9.18                                | 12.53                               | 15.31                               | 17.68                               | 19.8                                |
| 0.0625            | 9.22                                | 12.87                               | 15.73                               | 18.06                               | 20.15                               |
| 0.125             | 9.24                                | 13.12                               | 15.87                               | 18.25                               | 20.36                               |
| 0.25              | 9.3                                 | 13.14                               | 16.12                               | 18.62                               | 20.63                               |
| 0.5               | 9.18                                | 13.14                               | 16.12                               | 18.62                               | 20.8                                |
| 1                 | 8.45                                | 12.65                               | 15.79                               | 18.4                                | 20.66                               |
| 2                 | 6.55                                | 10.82                               | 14.13                               | 16.9                                | 19.32                               |
| 4                 | 4.15                                | 7.55                                | 10.48                               | 13.09                               | 15.47                               |
| 8                 | 2.27                                | 4.39                                | 6.39                                | 8.29                                | 10.1                                |
| 16                | 1.16                                | 2.31                                | 3.43                                | 4.54                                | 5.62                                |
| 32                | 0.59                                | 1.17                                | 1.75                                | 2.33                                | 2.89                                |
| 64                | 0.29                                | 0.59                                | 0.88                                | 1.17                                | 1.44                                |
| 128               | 0.147                               | 0.29                                | 0.44                                | 0.59                                | 0.72                                |
| 256               | 0.074                               | 0.15                                | 0.22                                | 0.3                                 | 0.36                                |
| 512               | 0.037                               | 0.073                               | 0.11                                | 0.15                                | 0.18                                |
4. Results
In this paper, the influencing factors of epoxy resin viscosity, leakage aperture, and grouting pressure on leakage velocity were studied. The main conclusions are as follows:

When a pipe hole begins to leak, the pressure in the pipe will drop rapidly, and the area of the hole is directly proportional to the drop in pressure. When the aperture is determined, the lower the viscosity is, the smaller the pressure drop will be, the higher the viscosity will be, the larger the pressure drop will be.

The numerical simulation results showed that the fluidity of epoxy resin hardly changes when the viscosity is lower than 1 Pa.s. When the viscosity is 1 and 10 Pa.s, the fluidity of epoxy resin decreases obviously, the pressure change range is the most obvious between the viscosity of 1 and 10 Pa.s.

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