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The Research of Tilt Fissure Grouting Characteristics with Flowing Water

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Abstract: The slurry spread rule in fissure is the theoretical basis of grouting technology. In order to study the rule in fissure, the model of tilt fissure grouting in condition of flowing water is derived according to Newton's law of friction resistance and force of equilibrium law. By analyzing the slurry spread rule of the influence of water flow and the tilt Angle ,we can conclude that spread radius is the largest when slurry spreads in dip slope ($\theta = 180^0$) and parallel flow , the spread radius is minimum when slurry spreads in escarpment slope ($\theta = 0^0$)and counter flow, escarpment slope and counter flow have bigger influence on spread radius, fissure inclination and the water flow all importantly influence the slurry spread, whose influence depends on the grouting pressure and static water pressure in fissure.

Keywords: Grouting technology, Dynamic water, Fissure dip Angle, Spread rule.

1. INTRODUCTION

In order to achieve better grouting effect and realize the slurry of grouting filling, controllability and stability, the research of the theory of grouting is particularly important, and the slurry spread rule in fissure is the theoretical basis of grouting technology. The rock is made of a large number of joints and fissures, which is complex and formed by different geological structure, the slurry spread rule in formation is very complex too, so it has important research value to set up scientific, reasonable and practical fissure grouting model.

At present, there are many models about fissure grouting at home and abroad. Scholars like Baker [1], Hassler.L [2–3] etc derived the spread model of fissure grouting, Luo Pingping etc [4] derived the slurry spread model of single tilt fissure. But all of them do not consider the influence of flowing water on it. Zhan kaiyu [5] etc derived the slurry spread model of single fissure with flowing water, but only considered the horizontal fissures. From the above analysis and result, we can conclude that presently fissure grouting models have their respective ranges, with great limitations, and all have different problems. More comprehensive factors should be considered to make the model more real and more easily to guide grouting.

The spread model considered flowing water of tilt fissure grouting is established by theories of deduction. We analyses the rule of slurry spread according to the model under the action of flowing water and tilt Angle. And get the influence of grouting pressure, fissure aperture and grouting viscosity on the spread radius. The model is a beneficial supplement in the field of grouting.

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2. THE PRESSURE DISTRIBUTION MODEL OF NEWTON SLURRY IN TILT FISSURE

(a) Basic assumptions: (1) Slurry is homogeneous fluid and can not be compressed, and it spreads in laminar state. (2)The flow velocity of slurry on the up and down surface of fissure is 0. (3) Slurry spreads that is only along the fissure and can not inflow pores in the rock; (4) Do not consider the change of flow velocity through flow process; (5) Slurry from grouting hole into the fissure will flow parallel to the fissure plane under the pressure.

(b) Pressure distribution model: The slurry is assumed to be Newton fluid, the slurry viscosity is η , severe is ρ_g , flow velocity is u , fissure opening is b , grouting hole radius is r_0 , grouting hole pressure is p_0 , the slurry force by flowing water is p_s . As shown in Fig. (**1**), slurry from

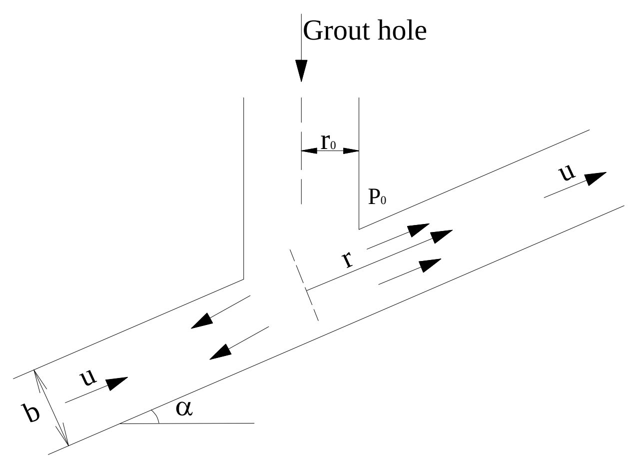

Fig. (1). Sketch of grouting with flowing water.

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grouting hole into tilt fissure flow parallel to the fissure plane, fissure dip Angle is α , azimuth is θ . As shown in Fig. (**2**), any fluid micro body is gotten out from the slurry, the external force which fluid micro body suffered are normal stress p and shear stress τ .

In the above assumptions, the sum of each component force along the radial direction of unit center shall be equal to 0.

$$\left\{(p+p_s)r\Delta\theta\Delta z-\left[(p+p_s)+\frac{d(p+p_s)}{dr}\Delta r\right].(r+\Delta r)\Delta\theta\Delta z\right\}$$
$$+\left[(p+p_s)+\frac{d(p+p_s)}{dr}\frac{\Delta r}{2}\right].\Delta r\Delta z\Delta\theta$$
$$+\left(\frac{d\tau}{dz}\right)\Delta z\frac{r\Delta\theta+(r+\Delta r)\Delta\theta}{2}\Delta r \tag{1}$$

Where: r is slurry spread radius at any time; p is fissure grouting pressure in the place of r ; $\Delta\theta$ is angle of the micro body is formed by increment of the spread radius in unit time; r is increment of the spread radius in unit time.

Simplify and omit high order trace, get:

$$\frac{d(p+p_s)}{dr}-\frac{d\tau}{dz}=0 \tag{2}$$

For tilt fissure we should consider the influence of gravity on the spread of slurry spread, so the equilibrium equation about the slurry radial cell cube with force is:

$$\left[\frac{d\tau}{dz}-\frac{d(p+p_s)}{dr}\right]r\Delta\theta\Delta r\Delta z+\frac{(2r+\Delta r)\Delta\theta}{2}\Delta r\Delta z\rho_g\sin\alpha\cos\theta=0 \tag{3}$$

Simplify and omit high order trace, get:

$$\frac{d(p+p_s)}{dr}-\frac{d\tau}{dz}=\rho_g\sin\alpha\cos\theta \tag{4}$$

The rheological curve of Newton fluid is a straight line through the origin[6], the equation is:

$$\tau=\eta\gamma \tag{5}$$

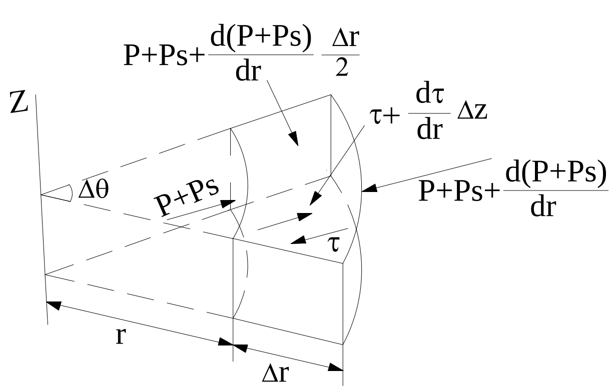


Fig. (2). Sketch of micro body stress.

Where: γ is Shear rate: $\gamma=-\frac{dv}{dz}$ substitute into the formula（5）get $\tau=\eta\left(\frac{dv}{dz}\right)$

Where: τ is Slurry shear stress; η is Slurry viscosity; $\frac{dv}{dz}$ is the speed rail slope of slurry at the direction of z

Integral (4, 5), get:

$$\eta\frac{dv}{dz}=\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right](z+C_1)$$

When boundary conditions $z=0$, substitute $\frac{dv}{dz}=0$ into the formula above, get $C_1=0$, and substitute $C_1=0$ into formula above, integral to z, get:

$$v=\frac{\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]}{2\eta dr}(z^2+C_2)$$

And when $z=\pm\frac{b}{2}$, get $v=0$ substitute formula above, get:

$C_2=-\frac{b^2}{4}$, so

$$v=\frac{\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]}{2\eta dr}\left(z^2-\frac{b^2}{4}\right)$$

Then get slurry average flow velocity $\bar{v}$:

$$\bar{v}=\frac{1}{b}\int_{-\frac{b}{2}}^{\frac{b}{2}}\frac{1}{2\eta}\left(z^2-\frac{b^2}{4}\right)\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]dz$$
$$=-\frac{b^2}{12\eta}\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]$$

Assume that slurry spread in shape is semicircular along the flow direction. Get quantity of slurry at unit time:

$$q=\pi rb\bar{v}=-\pi rb\cdot\frac{b^2}{12\eta}\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]=-\frac{\pi b^3 r}{12\eta}$$
$$\left[\frac{d(p+p_s)}{dr}-\rho_g\sin\alpha\cos\theta\right]$$

Integral the formula above, get:

$$p+p_s=-\frac{12\eta q}{\pi b^3}\ln r+r\rho_g\sin\alpha\cos\theta+C_3 \tag{6}$$

Substitute $z=0$, $\frac{dv}{dz}=0$ into the formula above, get:

$$C_3=p_0+p_s+\frac{12\eta q}{\pi b^3}\ln r_0-r_0\rho_g\sin\alpha\cos\theta$$

and substitute C_3 into formula（6）,get:

$$p = p_0 - \frac{12\eta q}{\pi b^3}\ln\left(\frac{r}{r_0}\right) + \left(r - r_0\right)\rho_g \sin\alpha\cos\theta \tag{7}$$

3. THE RESEARCH OF THE TILT FISSURE GROUTING SPREAD RADIUS WITH DIFFERENT FLOW CONDITIONS

The flow of the slurry in fissure has two directions: parallel flow and counter flow. When water is moving, the direction of parallel flow is like an open system, and the boundary condition when achieving maximum spread radius is $p = 0$, the direction of counter flow is like a closed system, and has calm water pressure P_J, so when achieving maximum spread radius the boundary condition is $p = p_J$.

(a) Slurry Spread in the Direction of Parallel Flow

Compared r with r_0, r_0 is very small, and it is small enough to be ignored. So we can ignore the influence of r_0 in the formula above, and get grouting quantity with the formula (7) and boundary conditions when $r = r$, $p = 0, p_s = 0$:

$$q = \frac{\pi b^3\left[p_0 + r\rho_g \sin\alpha\cos\theta\right]}{12\eta\ln\left(\frac{r}{r_0}\right)} \tag{8}$$

The grouting quantity at unit time is equal to the required amount of increasing grouting spread radius in that period, get: $\int_0^t q\,dt = \int_{r_0}^r \pi r b\,dr$, simplify the formula, then get:

$$t = \frac{6r^2\eta\ln\left(\frac{r}{r_0}\right)}{b^2\left(p_0 + r\rho_g \sin\alpha\cos\theta\right)} \tag{9}$$

Substitute (8) into the formula (9), get:

$$t = \frac{6r^2\eta\ln\left(\frac{r}{r_0}\right)}{b^2\left(p_0 + r\rho_g \sin\alpha\cos\theta\right)} \tag{10}$$

We notes the needed grouting time for T when spread radius achieves maximum, and simplify the formula above, then get:

$$r_{\max}\left[r_{\max}\ln\left(\frac{r_{\max}}{r_0}\right) - \frac{Tb^2\rho_g\sin\alpha\cos\theta}{6\eta}\right] = \frac{Tb^2 p_0}{6\eta} \tag{11}$$

Where : T is grouting time; $r_{\max}$ is maximum spread radius of the slurry

(b) Slurry Spread in the Direction of Counter Flow

The formula (7) and boundary conditions $r = r$, $p = p_J, p_s = 0$, get grouting quantity :

$$q = \frac{\pi b^3\left(p_0 - p_J + r\rho_g \sin\alpha\cos\theta\right)}{12\eta\ln\left(\frac{r}{r_0}\right)} \tag{12}$$

Substitute into the formula（9）, get:

$$t = \frac{6r^2\eta\ln\left(\frac{r}{r_0}\right)}{b^2\left(p_0 - p_J + r\rho_g \sin\alpha\cos\theta\right)} \tag{13}$$

We notes the needed grouting time for T when spread radius achieves maximum, and simplify the formula above, then get:

$$r_{\max}\left[r_{\max}\ln\left(\frac{r_{\max}}{r_0}\right) - \frac{Tb^2\rho_g\sin\alpha\cos\theta}{6\eta}\right] = \frac{Tb^2\left(p_0 - p_J\right)}{6\eta}$$

(14)

4. ANALYSE THE FACTORS OF INFLUENCING GROUTING EFFECT

Achieving ideal grouting effect is the most important goal in grouting engineering. Grouting effect is mainly decided by the slurry spread radius, so the research of slurry spread radius is particularly important. The factors have great influence on spread radius, which are water, fissure, grouting pressure, grouting time, fissure opening and so on.

In engineering, calm water pressure $p_J = 0.5kg/cm^2$, slurry viscosity $\eta = 20Pa$, grouting aperture radius $r_0 = 5cm$, slurry severe $\rho_g = 13.50KN/m^3$, other parameters are analysed as variables.

(a) Analyse the Influence of Water Flow and Grouting Time to Spread Radius

The very important question in the actual grouting engineering is that how much time is needed when spread radius reaches the demanded distance. When grouting pressure $p_0 = 3.5kg/cm^2$, fissure opening $b = 0.05cm$, fissure dip Angle $\alpha = 30^0$, draw outline curves of grouting spread and changed curves of spread radius with different grouting time as shown in Figs. (**3**, **4**).

We can know that the spread contour of slurry in tilt fissure approximates oval from Figs. (**3**, **4**). Spread radius is the largest when slurry spreads in dip slope ($\theta = 180$) and parallel flow. Spread radius is minimum when slurry spreads in escarpment slope ($\theta = 0^0$) and counter flow. And the difference of spread radius becomes bigger and bigger in both cases, which proves that it is conducive to spread when slurry spread in parallel flow and dip slope, it influences the spread radius more when slurry spread in escarpment slope and counter flow. With the extension of the grouting time, the growth trend of slurry spread is nonlinear, but the speed of increasing reduces gradually, and the curve tends to be gentle. Because the grouting pressure remains the same, pressure

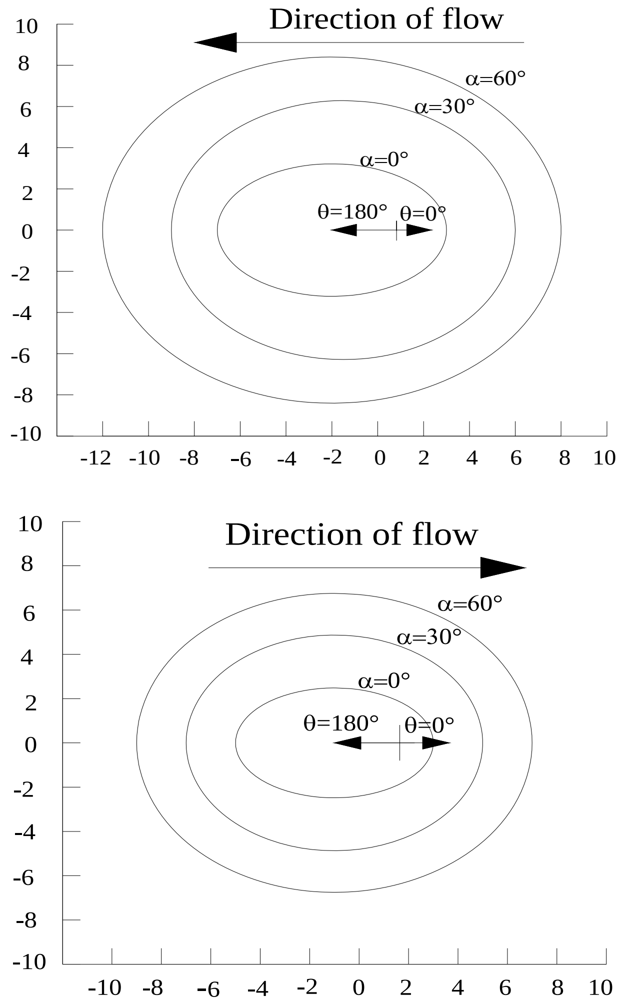


Fig. (3). curves of Slurry spread contour at different grouting time with flowing water.

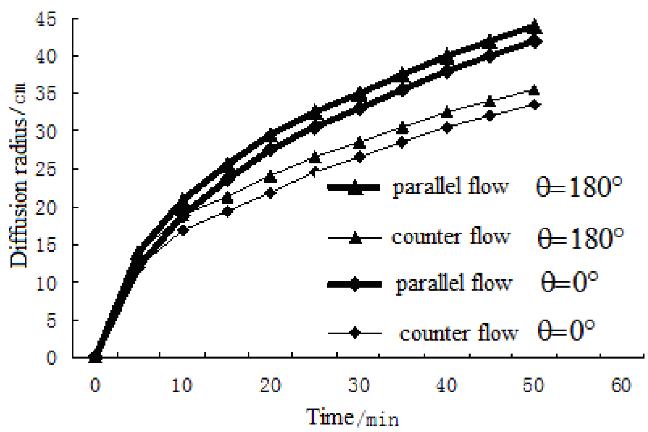


Fig. (4). Sketch of spread radius and time with flowing water.

gradient is smaller and smaller along with the increase of spread radius, the flow speed of slurry becomes more and more slow, grouting quantity also decreases, this is consistent with the actual grouting situation. So we can know there willbe a limit of spread radius when grouting pressure is constant. And with the increase of the spread radius of the slurry, grouting difficulty also accrodingly becomes bigger and bigger.

(b) Analyse the Influence of Pressure on the Spread Radius

When grouting, the grouting pressure is an important standard to judge the change of spread radius. Spread radius will also change accrodingly when grouting pressure changes. To master the relationship between the grouting pressure and spread radius will be very important for the actual grouting engineering.

In engineering, grouting duration $T = 60\,\min$, $\eta = 20Pa$, $r_0 = 5cm$, $b = 0.05cm$, we will draw and calculate the sketch of the grouting pressure and spread radius respectively under the condition of different flow direction by formula (11) and (14). As shown in Fig. (**5**).

From Fig. (**5**), we can know that spread radius will be growing when grouting pressure increases in the same fissure, but its growth rate gradually decreases. In condition of moving water, the required grouting pressure in counter flow is bigger than that in parallel flow when spread radius are the same, which shows parallel flow is beneficial to the spread of the slurry; the required grouting pressure in escarpment slope is bigger than that in dip slope when spread radius are the same, which shows dip slope is beneficial to the spread of the slurry. From formula (11) and (14) we can know, the influence of fissure inclination and water flow to slurry spread depends on the grouting pressure and fissures calm water pressure.

From Fig. (**6**) we can know that in the same direction of flow, self-weight effect of slurry increases gradually with the increase of fissure dip angle, the spread radius in the direction of dip slope increases, and decreases in the direction of escarpment slope. The spread radius in the direction of dip slope is 4m larger than that in the direction of escarpment slope when flow and fissure in the same direction and $\alpha = 60^0$; The spread radius in the direction of dip slope is 2m larger than that in the direction of escarpment slope when flow and fissure in opposite direction and $\alpha = 60^0$. The results of above analysis indicate that not only water flow influence the spread of the slurry, but also fissure dip Angle

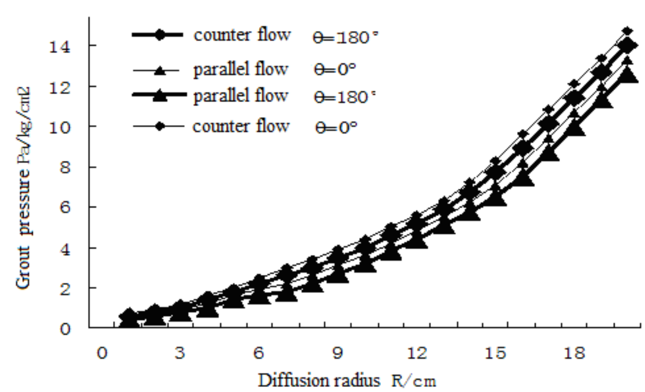
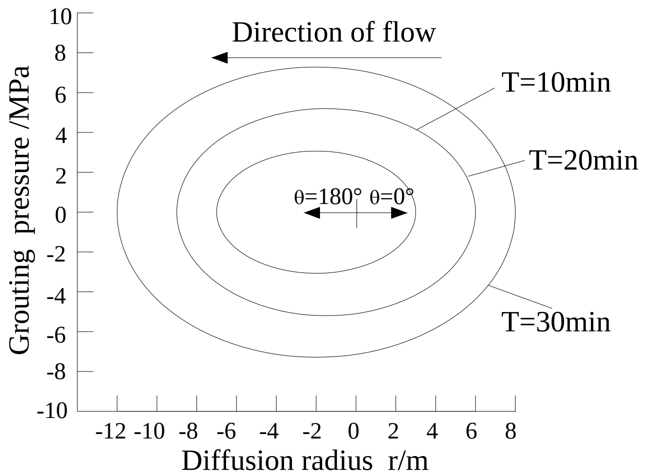


Fig. (5). Sketch of spread radius and grouting pressure with flowing water.



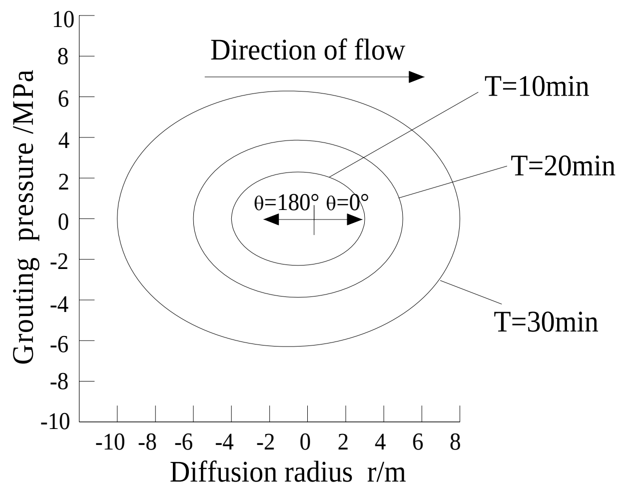


Fig. (6). the contour line of slurry spread with different Angle fissure when water flow and fissure inclination at the same direction or at the opposite direction.

has great influence on it, and we should pay more attention to shear dilution slurry in grouting engineering.

5. CONCLUSIONS

(a) Tilt fissure dynamic water grouting model is deduced according to Newton's law of friction resistance and force equilibrium law. Through analysising the model, we can conclude the relationship of slurry obliquity, spread radius, grouting time and grouting pressure in dynamic water condition. The model considers two factors of the water flow and fissure dip Angle that have never been considered, establishes more comprehensive model, concludes the more accurate slurry spread rule, provides favorable theoretical basis for the actual grouting engineering, and has very good guidance significance.

(b) The results of model analysis show that: the fissure of slurry tilt spread outline approximates an oval, the spread radius is the largest when slurry spread in dip slope ($\theta = 180^0$) and parallel flow, the spread radius is minimum when slurry spreads in escarpment slope ($\theta = 0^0$) and counter flow, and the spread radius is more affected when slurry spread in escarpment slope and counter flow. The growth trend of spread radius with the extension of the grouting time is nonlinear, but its speed of increasing gradually decreases, and it eventually reaches a limit radius.

(c) The spread radius with the grouting pressure increases in the same fissure, but growth rate gradually slows down. Dip slope ($\theta = 180^0$) and parallel flow are beneficial to the spread of slurry. Fissure inclination and water flow influence the speed of slurry spread, which depends on the grouting pressure and fissure static water pressure.

(d) Not only water flow influences the spread of the slurry, but also fissure dip angle influences, and we should pay more attention to shear dilution slurry in grouting engineering.

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