Study on the mechanism of breaking concrete by ultra-high pressure water jet

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Abstract. The concrete breaking mechanism of ultra-high pressure water jet is divided into two parts: the characteristics of ultra-high pressure water jet and the characteristics of concrete under the action of water jet. Through the analysis of the water wedge and water hammer under the action of the jet on the concrete breaking, ultra-high pressure water jet pressure and jet on the concrete strike force is a linear relationship.

Keywords: super high pressure; concrete; water jet.

1. Characteristics of ultra-high pressure water jet

The ultra-high pressure water jet is a kind of high-energy water jet, which is pressurized by a high-pressure pump to make the pressure reach hundreds or even thousands of megapascals, and ejects a high-energy water stream from the nozzle with special aperture at a very high speed of 100-1000m / s. The water stream has a very strong hitting power, and can cut, break, pierce, remove and clean various materials, etc . The working medium of ultra-high pressure water jet is water fluid. When processing metal materials, it will take away the heat generated and will not cause the rapid rise of workpiece temperature. It belongs to the category of cold processing and will not damage the structure of metal materials, and will not produce temperature stress and deformation. Ultra high pressure water jet technology has the advantages of environmental protection, no pollution, no damage to metal material structure, wide application and so on. The ultra-high pressure jet diffuses outwards in the shape of trumpet after being ejected through the nozzle, and its structure is divided into four stages: tight stage, core stage, rupture stage and water drop stage.

1) compact segment

This stage is a section of water flow just out of the nozzle. It is close to the nozzle. The shape is similar to the nozzle shape, tight, transparent and clear. The flow velocity at any point of the end face is the same and approximate to the outlet velocity.

2) core segment

This stage is a section of water jet after the water jet passes through the tight section. The flow velocity of the water jet still maintains the initial jet speed, showing a tight state. It is the main part of crushing, cutting and cleaning, so it is the core stage. Water jet will appear cracks in the air friction. Air enters the water jet through the cracks to form a large water mass, which makes the water jet present a trumpet shape.

3) rupture segment

In this stage, the large water masses formed in the core section enter more air, and the water masses become larger again and begin to break into water drops, also known as the basic section.

4) water droplet segment

This stage is the last stage of water jet from the nozzle, which basically has no breaking energy, and the end face forms water drop in the air friction.

2. Water wedge effect of super high pressure water jet on concrete

The damage of super high pressure water jet to concrete includes two forms: water wedge action and water hammer action. Water wedge action refers to that when the sand and stone aggregate in the internal structure of concrete are close together and there is water drop on the concrete surface, the aggregate will absorb the water drop into the joint between the aggregates by using its own characteristic adsorption force, so as to expand the crack and crush the concrete.

When the water drops on the concrete surface, the speed of the water drops will change after being blocked, which will cause the pressure inside the water drops and the stress field contacting the concrete surface to change. When the water drops act on the concrete surface for many times, the structure of the concrete surface will be damaged. As shown in Figure 1, the water drop acts on the concrete.

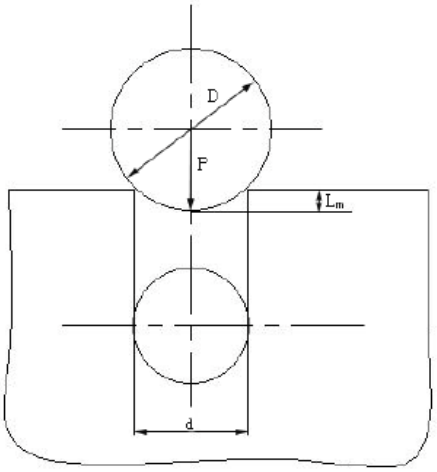

Fig. 1 schematic diagram of water drop impacting on material

Its kinetic energy is:

$$E_k = \frac{mv^2}{2} = \frac{\pi\rho D^2 v^3}{8}$$

Where m is the mass of water drop, V is the speed of water drop, and D is the diameter of water drop.

The average stress in the concrete is:

$$\sigma_{avg} = \frac{p}{\pi D L_m} = \frac{Dv^3 p}{8L_m^2}$$

Where LM is the penetration depth of water drop into the material, π DLM is the contact area between the water drop and the material.

$$L_m = \sqrt{\frac{Dv^3\rho}{8\sigma_{avg}}}$$

3. water hammer effect of super high pressure water jet on concrete

Water hammer is a kind of continuous hydraulic damage to the material formed in the water flow system after the water is pressurized by a high-pressure pump. When the ultra-high pressure water jet impinges on the concrete surface, it will produce high pressure stress on the impact point, which will change the

concrete surface structure and produce cracks. As shown in Figure 3-1, the deformation of concrete surface caused by the impact force of water jet. The action stress between the aggregate inside the concrete material will increase according to the increase of the pressure, and the maximum shear stress will be formed near the impact point. When the shear stress is greater than the critical value, the concrete microcracks will increase with the increase of the external load, which will promote the rapid development of the concrete microcracks, and the internal structural particles will quickly separate the body until the failure.

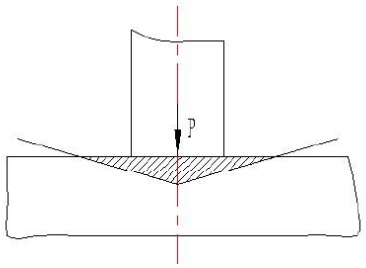

Figure 2. water jet impact on concrete

When the jet impinges on a broken object, the force acting on the surface of the object will change with the change of velocity and impact angle:

$$F = \rho q v(1-\cos\beta)$$

Where f is the impact force of water jet on the object, N; ρ is the fluid density, kg / m^3; q is the jet volume flow Volume, m^3 / s; V is jet velocity, m / s; β is jet direction change angle.

From the above formula, when $\beta \approx 180^\circ$, the jet reflects completely, and the impact force F will reach the maximum value, that is, f = 2 ρ QV. After derivation:

Where f is the jet striking force, N; D is the nozzle diameter, mm; P is the jet pressure, MPa.

The striking ways of water jet usually include oscillating jet, geometric jet, pulse jet and so on. The oscillating jet is a kind of sharp "oscillating jet axe" formed by the water jet oscillating back and forth with the nozzle and adding a certain frequency of mechanical vibration. The oscillating jet has the characteristics of cluster attack, and maintains a high impact force and crushing efficiency in the effective range of amplitude and frequency. Geometric jet is a kind of central jet which has a coupling relationship. Its impact force is concentrated on the center of the object, so that the amplitude is much larger than other jet modes, which is helpful to improve the crushing efficiency. The pulsed jet is a discontinuous jet.

The state of the jet is like the bullet of shooting. When the pulse jet strikes the object, there will be stagnation pressure, which greatly reduces the specific energy of cutting. Based on the characteristics of shaking jet, geometric jet and pulse jet, the multi-dimensional orthogonal jet is proposed to study the method of breaking concrete efficiently. When the impact pressure appears on the concrete surface, the peak pressure pH of the water jet pulse will be much greater than the stagnation pressure P, and its magnitude is as follows:

$$p_H = \frac{\rho a u}{1+(\rho a / \rho_s a_s)}$$

Where ρ s is the density of concrete, kg / m^3; ρ is the density of water, kg / m^3; u is the impact velocity of jet, m/s; as is the sound velocity in concrete, m/s

4. Analysis of the mechanical properties of concrete under the action of ultra-high pressure water jet

Ordinary concrete is a mixture of cement, coarse aggregate (gravel, pebble), fine aggregate (sand), additive and water, which is used to make stone. Aggregate is the skeleton of concrete, which plays a supporting role. Cement slurry wraps the aggregate and fills the cracks between the aggregates. Before the overall hardening of the concrete, it has a lubricating effect, which makes the concrete mixture have

better fluidity. After the hardening of the concrete, the cement slurry and the aggregate are bound together, forming a strong, shaped and dense whole.

After hardening, there is a weak part in the structure of concrete, that is, the interface between aggregate and cement slurry -- transition area; the newly mixed concrete will have a layer of water film with high water cement ratio around the aggregate, which will produce more crystals and large gaps in the skeleton structure; the crystal plate structure of concrete will change with environmental factors and organizational structure to form a take-off area The transition zone, structure and orientation layer in concrete will produce microcracks due to solidification and shrinkage, which will affect the strength of concrete, and the microcracks will continue to expand under the action of tensile force, shear force and pressure until they are broken.

When the ultra-high pressure water jet breaks the concrete, the damage and deformation of the concrete itself will go through four parts:

The first part is fracture convergence and pore closure. This part is the strengthening process of concrete, the internal structure will also change, the internal microcracks and pores will be closed under pressure, the concrete matrix will be elastically compressed, and the stress-strain curve will show a downward convex state.

The second part is the linear elastic response process of concrete. In this process, the local stress of concrete is small, and the microcracks in concrete will not change. The relationship between stress and strain is linear elastic, and the curve shows a linear state. The third part is the stable development process of microcracks. In this process, there is inelastic deformation in the concrete, internal microcracks develop and expand, and the stress-strain curve presents bending state. In the on-line elastic fracture mechanics analysis of concrete internal crack, when the stress on the crack tip occurs, the tangential tensile stress will appear perpendicular to the loading direction.

The fourth part is crack penetration and unsteady propagation. When the cracks inside the concrete become larger to a certain extent, the cracks begin to diverge and run through, forming large cracks. In this stage, the stress begins to decrease, the material softens and deforms, and then the macro cracks get further development and changes, so that the shape of the material changes from compression to shape, Poisson's ratio increases, and the material state appears obvious inelastic deformation.

5. Conclusion

In this paper, the breaking mechanism of concrete super high pressure water jet is analyzed from two aspects: the characteristics of super high pressure water jet and the mechanical properties of concrete. The fracture of concrete by jet under the action of water wedge and water hammer is analyzed, which lays a theoretical foundation for the further study of subsequent collection of sample data.

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