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Effect of steel fiber on the shear strength of reactive powder concrete

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Effect of steel fiber on the shear strength of reactive powder concrete

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Abstract. Nowadays, research about concrete technology has led to a concrete with high performance (ultra-high concrete). Various innovations are also used to support the ultra-high concrete. In concrete engineering, we always avoid shear failure due to its brittleness. In this study, innovative additives will be used in the form of fiber steel fiber with the aim to increase the shear strength of the concrete powder. Tests in the laboratory will be carried out on samples of fiber-reinforced concrete beam specimens and to study the effect of increasing shear strength due to the addition of fiber (steel fiber), the variable is aspect ratio (fiber length versus fiber diameter) varied 75, 100, 125,165,180 and volume aspects (0.1%, 0.2%, 0.3, 0.4, 0.5%, 0.6%). And the greater the percentage of steel fiber volume can increase the shear strength, the greater the fiber-reinforced concrete, but the workability will be lower. In order for workability to remain good, the recommended fiber volume is 0.3% and the aspect ratio using the critical length of the fiber compared to the diameter of the fiber.

1. Introduction

The design of reinforced concrete building structures in the present has undergone so many changes to a better result, this is because the quality of the concrete has led to ultra-high concrete. Thus, the dimensions of the section size of reinforced concrete structures can be designed smaller than before. Efforts to achieve high quality concrete through the use of innovative materials such as powder concrete, polymer concrete, high density concrete etc. One of the innovative additives that increase the tensile strength of concrete is steel fiber. Several studies that have been carried out on these innovative materials show improvement in concrete quality and tensile strength of concrete.

Research that has been carried out using steel fiber in concrete is focused on improving the quality of concrete. An innovative thought is obtained from the use of steel fiber to increase the concrete shear strength. This is based on the increase in tensile strength on concrete from steel fiber can also increase the shear strength of the concrete, so that the concrete section has an increase in shear capacity in carrying the shear force.

This study aims to contribute that steel fiber can improve concrete shear strength and can be used in planning in the design of reinforced concrete structures such as pile cap planning, corbel which requires concrete with high shear strength.

2. Fiber Reinforced Concrete

Fiber-reinforced concrete is a mixture of concrete that is added to the fiber evenly, both in the form of long fibers and short fibers. The basic idea of adding fiber is to prevent the propagation of cracks in concrete in the tensile area due to loading (Soroushian, Bayasi, 1987). Based on research conducted by Ramakrishnan in 1988 (Sudarmoko, 1990) it was found that adding fiber to the mixture would reduce workability quickly in line with the increase in fiber concentration and fiber aspect ratio. Graphs of strain stress of normal concrete and fiber-reinforced concrete can be seen in Figure 1.

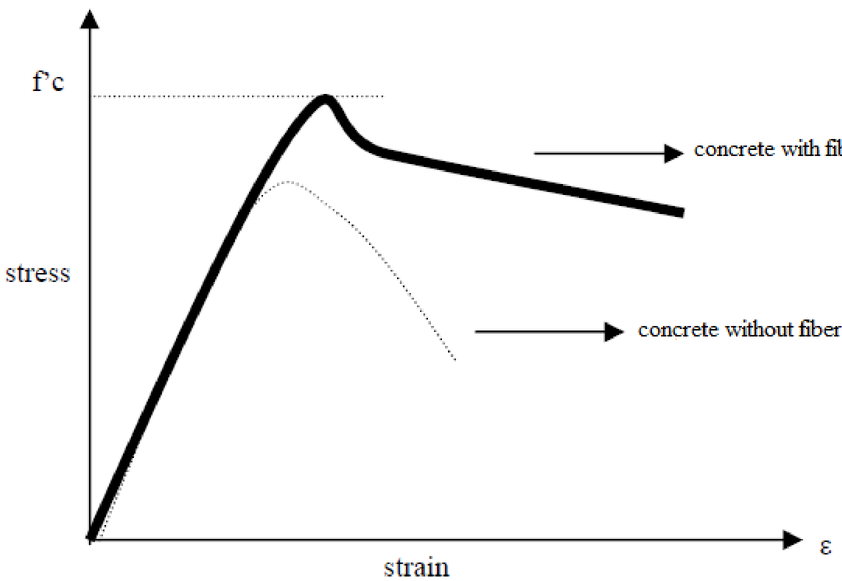

Figure 1. Comparison of Normal Concrete Strain and Fiber-Reinforced Concrete Charts. (Source: Sukoyo, 2011)

There are several factors that influence fiber efficiency, that is the critical length of fiber and the volume of fiber in the concrete mixture. In this study the length of fiber was analyzed based on the formula of critical length of fiber with a volume of fiber addition of 0%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, and 0.6%. The fiber used in this study is a soft stainless steel type 201 show in Table 1.

Table 1. Technical Data of Stainless Steel Soft 201

Properties of Stainless Steel Soft 201	
Density	7.80 gr/cm^3
Hardness	95
Tensile strength, ultimate	750 Mpa
Elongation A50mm	40%
Modulus of Elasticity	200 Gpa

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Shear modulus	86 Gpa

The main role of fiber occurs after the concrete has been cracked (post-cracking) as its function is to channel cracks that occur in the concrete. In the design of fiber-reinforced concrete, 2 main functions of fiber after cracked concrete according to Bentur and Mindess (1990) are:

- Increases composite strength higher than concrete by channeling stresses and loads that cause concrete to crack into fiber
- Increases composite toughness by absorbing mechanical energy

Critical length (lc) is the minimum length of fiber in a diameter of the fiber needed to reach stress when it is failed (Schwartz, 1984). Calculation of lc values is based on the assumption of a stress transfer mechanism as in Figure 2 curve shows the mechanism of transfer of elastic stress due to friction.

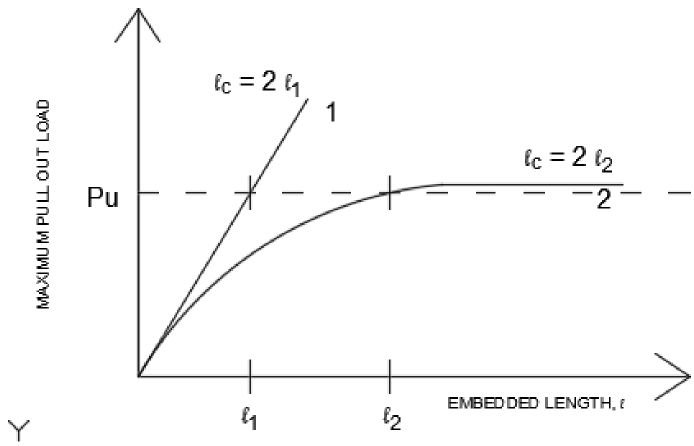

Figure 2. Pull out vs. long curves (Source: Clash & Mindess)

Figure 3 shows that if l = lc the maximum load on the fiber is centered on the center point of the fiber length.

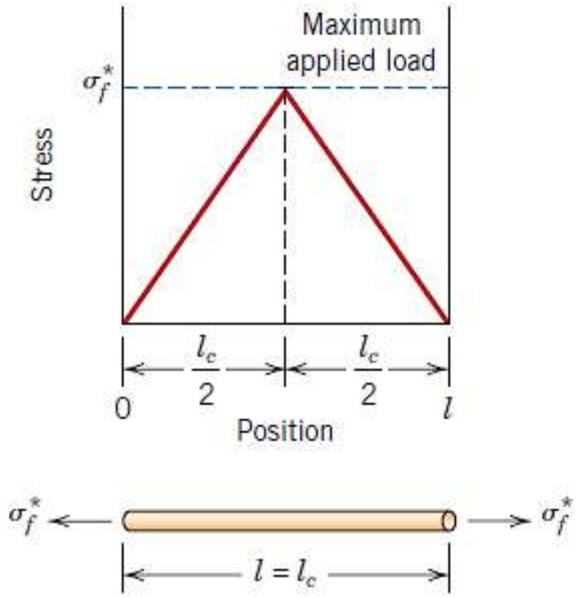

Figure 3 Stress along fiber as a function of fiber length (l = lc) (Source: Bentur & Mindess)

In Figure 4 shows that if l <lc, the length of the fiber is not sufficiently embedded in the concrete which causes the resulting stress is not the same as the strength of the fiber and produces an inefficient fiber strength.

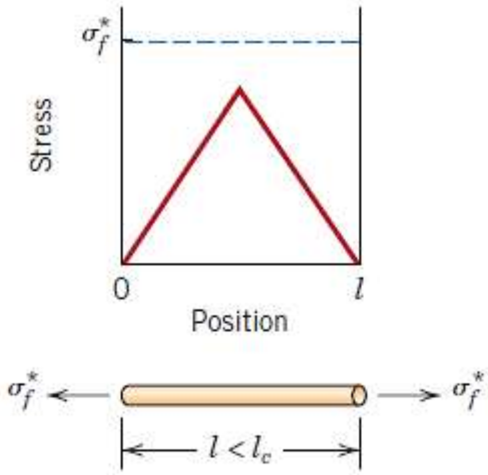

Figure 4. Stress along the fiber as a function of fiber length (L <Lc) (Source: Bentur & Mindess)

If the fiber length is longer than the lc the fiber stress is mostly melted as in Figure 5, so some fiber capacity can be utilized.

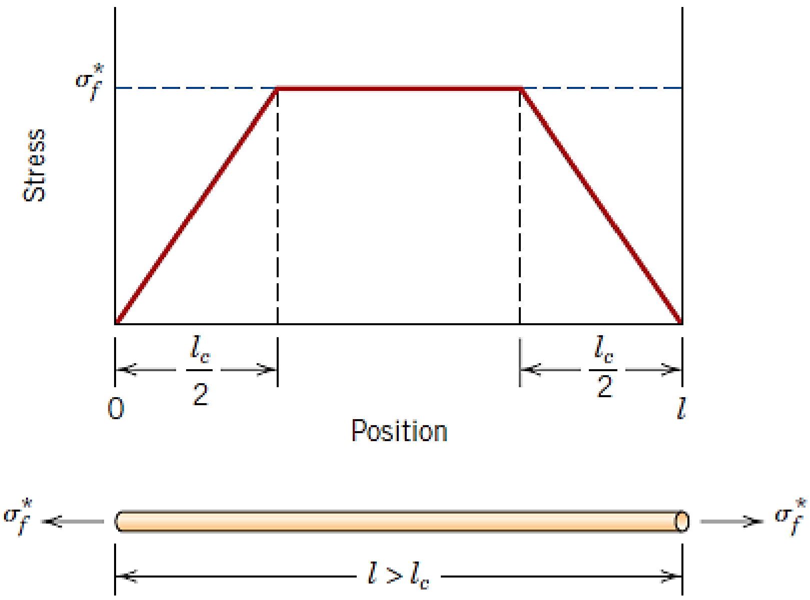

Figure 5. Stress along the fiber as a function of fiber length (L> Lc) (Source: Bentur & Mindess)

To calculate lc due to stress transfer according to Bentur and Mindess (1990) is:

$$lc = \frac{\sigma_{fu}.r}{\tau_{fu}} \quad (1)$$

where,
l_c = critical length
σ_{fu} = ultimate tensile strength
r = fiber radius
τ_{fu} = maximum friction shear stress (shear stress) or bond strength between fiber and concrete as in Figure 6.

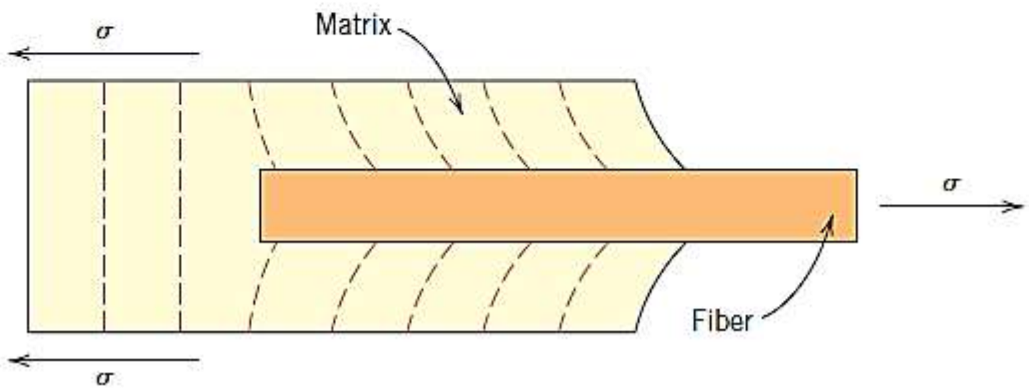

Figure 6. Deformation patterns in concrete affect fiber

The formula used to calculate the maximum friction (bond stress) shear stress can be seen in Table 2.

Table 2. *Pullout Strength of Single Fiber*

Fiber type	Matrix	Pullout strength
Straight	Concrete	$\tau_{f,max} = 0.396\sqrt{f_c'}$ (MPa) [$4.77\sqrt{f_c'}$ (ksi)]
	Mortar	$\tau_{f,max} = 0.330\sqrt{f_c'}$ (MPa) [$3.97\sqrt{f_c'}$ (ksi)]
End-hooked	Concrete	$\tau_{eh,max} = 0.825\sqrt{f_c'}$ (MPa) [$9.94\sqrt{f_c'}$ (ksi)]
	Mortar	$\tau_{eh,max} = 0.660\sqrt{f_c'}$ (MPa) [$7.95\sqrt{f_c'}$ (ksi)]

In this study using RPC concrete, so that the maximum friction shear stress is taken the mortar formula and the type of fiber used is straight. Because of that, τ_{fu} used is 0,33 $\sqrt{f'c}$.

To get optimal results there are two things that must be considered carefully, first, fiber aspect ratio, namely the ratio between fiber length (l) and fiber diameter (d), and second, fiber volume fraction (Vf), which is the percentage volume fiber added to each unit of concrete volume. (Suhendro, 1990).
The volume of fiber added also has a role in increasing the strength of the concrete. Based on several studies that have been carried out, the addition of fiber volume also contributes to the strength of concrete, but decreases the level of workability. The results of the study of fibrous concrete bending beams prove that flexural behavior can be improved by increasing the fiber volume fraction (Figure 7) or by a fixed volume fraction, but by increasing the fiber aspect ratio, but causing fibers difficult to spread evenly in the concrete.

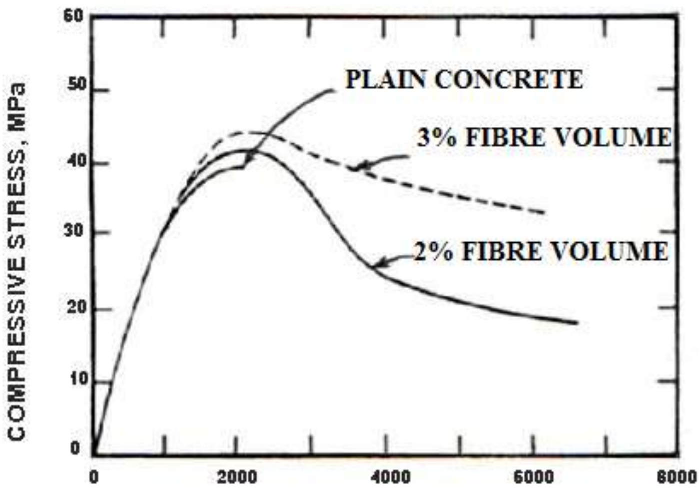

Figure 7. Strain stress curve on fiber-reinforced concrete press

According to Dipohusodo (1994), tensile stress with large variations and slope, both as a result of shear alone / flexural combination, will arise at any place along the beam, which must be taken into account in analysis and planning. Shear events on concrete blocks without reinforcement, generally damage occurs in the area along approximately three times the effective height of the beam, and is called a sliding span. As shown in Figure 8 below.

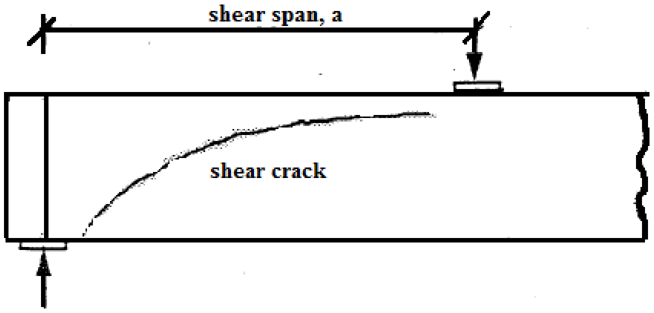

Figure 8. Typical damage due to diagonal tensile

Cracks due to diagonal tension are one of the ways to cause shear damage. Shorter shear span, damage arises as a combination of shifting, crushing and splitting, while for non-reinforced concrete beam with longer shear span, cracks due to bending tensile stress will occur before cracking due to diagonal stress. The occurrence of bending tensile cracks on a beam without reinforcement is an early warning of shear damage.

Skewed cracks due to shear in the reinforced concrete beam can occur without cracks due to flexure around it, or it can also be a continuation of the flexural crack process that has preceded it. Basically there are three types of cracks in the beam:

- Flexural Crack, occurs in areas that have a large bending moment value. The direction of the crack is almost perpendicular to the axis of the beam.
- Flexural Shear Crack, occurs in the part of the beam that has previously been flexed. Thus bending shear cracks are propagation of sloping cracks from flexural cracks that have occurred before. The process of bending cracks generally tends to propagate from the edge into the beam with almost vertical direction. The process continues without resulting in reduced stress until a critical combination of flexural and shear stresses is reached at the end of one of the deepest cracks, where a large shear stress occurs which then results in a tilted crack.
- Web Shear Crack, occurs in the cross section neutral line area where the maximum shear force and axial stress are very small. In this type of crack, sloping cracks on the beam do not experience flexural cracks before. This crack is rarely found in ordinary reinforced concrete beams and is more often found in I-shaped prestressed concrete beams with thin bodies and wide wings. Body shear cracks can also occur around the deflection turning point or in a place where there is a continuous termination of the span beam reinforcement.

3. Shear Strength Testing Model

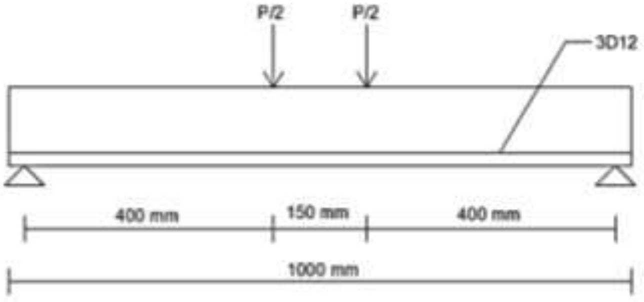

Figure 9. Modeling test objects

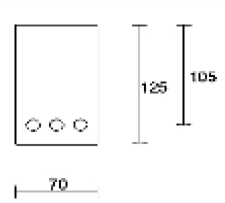

Figure 10. Beam cross section

Table 3. Data of the test object

Concrete: fc' = 50 MPa	Steel reinforcing : fy = 397 MPa	Longitudinal steel: 3D12 Without Transversal reinforcement
fiber: steel fiber fu = 836 MPa Volume of fiber: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% Length of fiber: 33 mm, 36 mm, and 39 mm		

$$V_n = V_c + V_f + V_r \quad (2)$$

where:

V_u = Ultimate shear force due to selfweight and Force P
V_n = Nominal shear force
V_c = contribution shear force by concrete
$= \frac{1}{6}\sqrt{f_c'}\, b_w.d$
V_r = contribution shear force by longitudinal reinforcing
V_f = contribution shear force by fiber

4. Testing Results

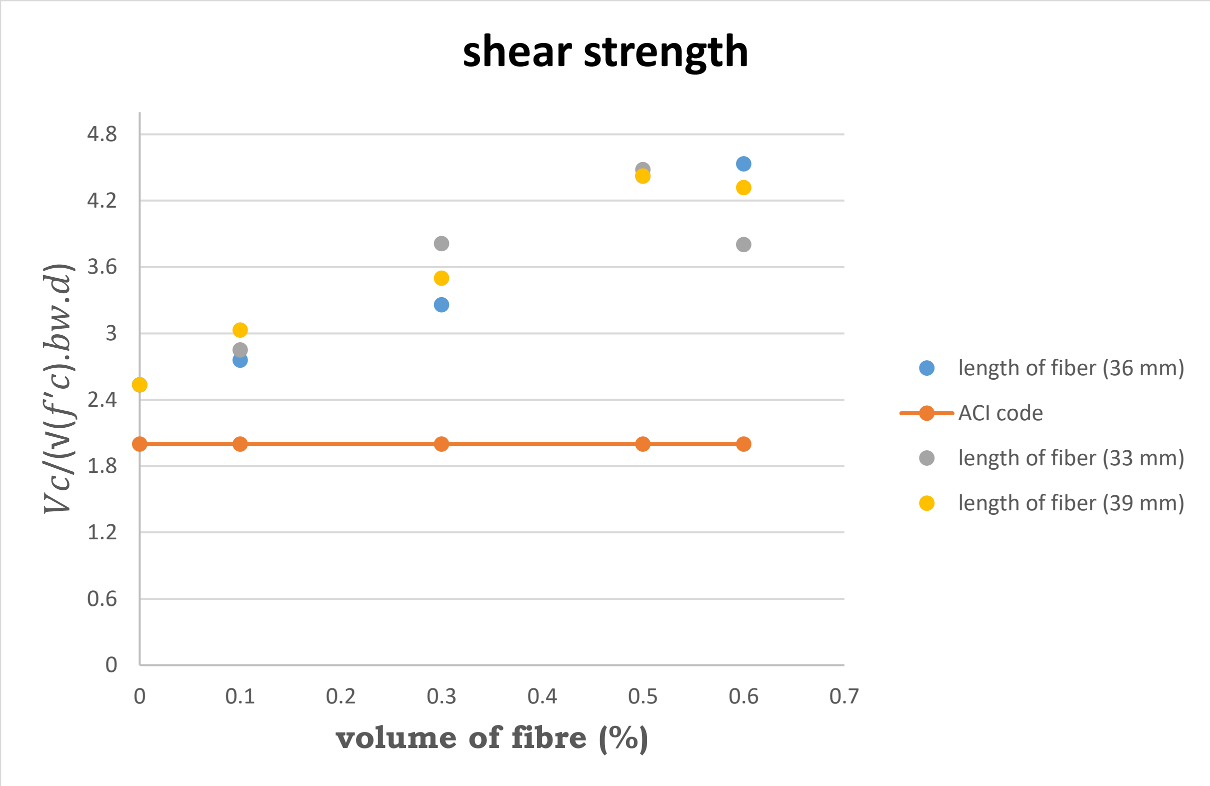

Figure 11. The relationship of shear strength to volume of fiber

Analysis of Research Results :

- It can be seen that the greater the volume of fiber provided, the greater the contribution of the shear strength of the fiber.
- For fiber volume of 0.6% with an aspect ratio of 165 and 180, the concrete beam has a decrease in Vf value. This is because the workability of the concrete fiber has been very low due to the volume of fiber mixed into the concrete is too large and has caused the fibers to clump only in certain parts (not evenly distributed).

5. Conclusion

Based on the results of the testing, conclusions were obtained, that are:

- Addition of fiber can increase the shear strength of concrete because the fiber has a high tensile stress.
- The greater the percentage increase in fiber volume, the greater the shear strength of the fiber from the fiber will increase.
- The greater the percentage increase in fiber volume will cause lower workability.
- For effective use (no slip occurs) it is recommended that the fiber length be the same as the critical length of the fiber (lc).
- In order for good concrete workability, the percentage of fiber volume is recommended at 0.3%.

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