Çelik Elyaf Takviyeli Betonun Kırılma Mekaniği

Fracture Mechanics of Steel Fiber Reinforced Concrete

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ÖZET

Betonun liflerle güçlendirilmesi, betonun çatlak oluşumuna karşı dayanıklılığını ve esnekliğini arttırmanın etkili bir yoludur. Lif betonlarında, kırılma mekaniği, çekme dayanımı, kırılma enerjisi ve tokluk analizinde bir prensip olarak kullanılır. Kırılma enerjisi, elementi çökmeye getirmek için gerekli olan enerjidir. Dayanıklılık değeri, normal gerinim-gerinme eğrisi altındaki alana eşittir. Kırılma mekaniği parametrelerinin (tokluk, kırılma enerjisi) boyut etkisi prensipleri ile çalışarak, özellikle özel betonlarda ve dolayısıyla lifli betonlarda birçok nedenden dolayı elde edilmesi büyük yarar sağlar.

ABSTRACT

The strengthening of concrete with fibers is an effective way to increase the resistance and ductility of concrete against crack development. In fiber concretes, fracture mechanics are used as a principle in the analysis of tensile strength, fracture energy and toughness. Fracture energy is the energy that will be required to bring the element to the collapse. The value of toughness is equal to the area under the usual strain-strain curve. It is of great benefit to obtain the fracture mechanics parameters (toughness, fracture energy) by working with the principles of dimension effect, especially on special concretes and thus on fibrous concretes for many reasons.

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Introduction

Tensile stresses cause a number of cracks to spread through a crack, causing concrete to migrate. These fissured cracks give rise to the effect of size. However, in order to create tensile stresses, it is not necessary to carry out tensile loads. As in this study, tensile stresses will also occur in the elementary critical sections in a direction perpendicular to the pressure loading, and even with shifting and pulling effects as a result of the pressure loading, a displacement of mixed elements will occur. Therefore, the effect of size effects on pressure loading and mixed mode collapses is of great importance. The modulus of elasticity of fiber concrete, which is higher than concrete, is added to the concrete, various material criteria (fracture mechanics parameters) such as toughness and breaking energy of the concrete are improved. Especially when the concrete starts to break, ie, starts to move away from the linear-elastic region, the fibers play a much more effective role and increase the breaking energy considerably. In addition, in the case of loading close to the fracture load, there are fewer cracks in the normal concretes than in the fibrous concretes, but the opening and the cracks in the fibrous concretes are spread in the element volume and there are no excessive localized cracks. The situation close to this ideal prevents the cracks to accumulate in a region and turn into a slit and lead the element to early immigration. (Van Chanh, 2004)

Fiber concrete has a very different characteristic than traditional concrete in terms of its behavior and performance. The difference in behavior is due to the fact that the fibers, which have a nice distribution in the concrete, perform their functions by transferring the stresses at the end of the cracks to the tops or the solid areas at the time of the formation of the cracks. In this way, the formation and growth of cracks which will lead to the demolition of concrete is prevented; breakage occurs at larger loads. Among the advantages of fiber concretes are the increased strength of the composites due to their high resistance to abrupt loads or repetitive loading and the increased amount of energy that can be swallowed under load. From the literature, it is seen that steel, nylon and composite fibers do not affect the mechanical properties such as compressive strength and modulus of elasticity. As the strength of the steel wire increases, the fracture energy increases. Similarly, the characteristic aspect, which is also a fracture mechanics parameter, is also growing. (Song, 2004)

Fracture Mechanics and Size Effect

As a result of crack formation in the concrete element, energy is required for collapse. Physical starting of the crack depends on the stress. The stress forms the fracture energy defined by the surface energy of the solid for crack formation. For this reason, energy criterion should be used in the calculation of the crushing mechanism. This criterion is necessary for physicists. Other methods, the method of safety stresses or the carrying power, do not use energy for migration. There are four major cases in the research area of fracture mechanics where safety stresses or bearing power methods do not take into account in the failure mechanisms of structures. (Soroushian, 1990)

1. Material strength is exceeded at different times in different points of the crash surface.
2. With the development and spread of the crack, softening is seen after the biggest load.
3. The large structure cracks are localized in a much smaller area than the section size. This brings the behavior closer to the linear elastic fracture mechanics (LECM).
4. Localization and energy release are handled by the fracture mechanics.

Depending on the load-displacement diagram, there are two types of structural failure, namely elastic and plastic. The typical characteristic of the plastic migrator is the simultaneous development of the dispersion of the various parts of the structure, proportional to a single parameter, as a single degree of freedom. These migrations are indicated by the long run-off plate in the load-displacement curve. If the load-displacement curve does not have such a flow plateau, the failure is not plastic, but brittle (or semi-friable). In fact, material deterioration is observed due to breakage, cracking and other damage, and the flow plate is destroyed, and the downfall does not develop as a single degree of freedom system. Although ductile collapse is desired, it is inevitable to have brittle collapse in the elements with 98% concrete, such as reinforced concrete, and no flow plateau.

Concrete and reinforced concrete elements which exhibit semi-crisp behavior have a softening zone after the largest load. In this region, a more brittle or more ductile behavior appears in relation to the element size, which is not taken into account in the safety stresses or in the conveying power methods. The area under the load displacement curve gives the energy absorbed by the structure during the collapse. This energy is particularly important in dynamic loading and creates the ductility of the structure. Plastic analysis does not provide information on the reduction of the largest load (softening mentioned above) and energy ingested. Therefore, the effect of the dimensionality of fracture mechanics and its easy application is being investigated by researchers. (Kim, 2002)

Some of the studies in the literature related to the dimension effect are: Dimension effect in diagonal shear decay in beams, in beams reinforced with external rods and plates, etriye and aggregate size in variable beams and in ashesless beams. Stapling effect on slabs, high-strength edge-notched beams in three-point loading from the two sides of the edge notched beams and slip stretching. The effect of dimension in the tests was examined. In pressure relief of reinforced concrete beams, reinforced concrete reinforced concrete beams, pressure loading of double cantilever samples and different delicate, notched and concrete cylinders under pressure loading. The effect of size and pressure on pressure decay was investigated in normal and high strength concrete cylinders with different notches and cavities. (Banthia, 2007)

Evaluation of Steel Fiber Reinforced Concrete Fracture Mechanics Perspective

Lean concrete is a brittle material which has low tensile strength, negligible structure in structural design, high toughness and ductility. In normal concretes, the energy required to spread any cracks is low. The addition of steel and / or synthetic fibers to concrete removes these handicaps of concrete. With the use of fibrous concretes, in fact, the inclusion of randomly dispersed discontinuous fibers into the composition consisting of fine aggregates, water, cement and additive, it is intended to control the crack growth and thereby increase toughness. In the 1960's, particularly in the UK and Scandinavian countries, fibrous concrete technologies have emerged and developed as a result of the search for different types of building materials, which are more economical than their metal structures. In fact, the straw-reinforced clay mortar (mudbrick), a source of inspiration for fibrous concretes, has been used as building material since 4500 years ago. Similarly, in bricks and mortar, goat hair, horses and even human hair fibers were used. As from the beginning of the 1900s, asbestos fibers were used in concrete for similar purposes. Today, although it does not completely add additives due to the fact that it does not enter into chemical reactions with concrete components, steel fibers of various sizes are used as a kind of concrete admixture as well as chemical and mineral substances. In recent years, steel fiber reinforced concrete has been widely used in highways, tunnel pavements, concrete pipe and concrete frameworks, because of its positive effects on concrete strength (especially tensile strength and tensile strength). The use of steel fiber in the mixture will positively contribute to the major mechanical characteristics mentioned below, especially since it will delay the formation and progression of crack formation under bending and pulling, and therefore also to the stress exposed elements. (Thomas, 2007)

Steel fiber concrete also shows pressure ductility. In other words, it has the ability to carry the load even when it reaches the carrying power. In addition, it has high resistance to shear, torsion and fatigue. Fractures, shedding, fragmentation and dispersions are few. If the fibers are evenly distributed and there are no gaps in the concrete, there is also a certain increase in the compressive strength of the fibrous concrete. Because the fibers perpendicular to the loading plane do not undertake any function in the compressive stress, even when they are subjected to a negative function due to their torsion and gap-increasing orientation, the fibers parallel to the loading plane increase the pressure stress and the ductility. In tensile strength, significant increases are observed in fiber concrete compared to normal concrete. Generally, when steel fiber concrete is used in construction applications, steel fiber is added not only to prevent breakage but also to prevent shedding, disintegration and dispersion of material to increase dynamic loading or impact strength. In addition, the shear strength of steel fiber concrete is much higher than that of normal concrete. Therefore, the use of cutting or torsion elements seems to be quite advantageous. Especially in high beams, reinforced concrete silos and earthquake curtains use is very significant. (Baloch, 2005)

Normal concretes can make limited amounts of deformation under stress and the system will migrate as a result of load increase. The fibers provide the ability to keep cracks at a limited level and to give higher deformation to the concrete by means of tensile transfer. Due to the stress transfer in the fibrous concrete, more energy is needed than the energy required to form the crack in order to spread the crack. This facilitates the formation of new cracks in the intact regions instead of spreading the crack. Thus, more energy is damped. The composite can make more deformation without migration. In the case of steel fiber concrete, the fibers perpendicular to the discharge load axis increase the toughness due to their tensile strength in parallel direction and the lateral deformations due to the adherence and high tensile capacities formed by friction between the concrete and the matrix. For these reasons, the same situation cannot be achieved at very high levels in the concretes containing polypropylene fibers. The most important difference between reinforcement and steel fibers is how and when they perform the functions in the concrete and the control of cracks there. Steel fibers are the materials that change the structure of the concrete and push the concrete to a plastic behavior. The feature of steel fiber concrete is its increased elasticity and energy absorption ability. Thus, in the case of fibrous concretes, the deceleration rate of the load is much slower than the normal concretes due to the increased deformation after maximum load. The resulting deformation is therefore much larger in steel fiber concretes. In fibers reinforced concrete, the fibers have more efficiency after the formation of cracks in the matrix. The post-cracking strength depends on the fiber length, shape and dimensions, and the stress-strain properties. Although there is no significant increase in the final load due to these reasons, the fibrous concrete can be more ductile under uniaxial loading. In addition, the first crack strength of a fibrous concrete with a uniform distribution of fibers and a low gap is high. Short-cut fibers, homogeneously dispersed in concrete, delays the formation of cracks, crack propagation and progression in concrete. Gradually increases the energy absorption capacity of concrete by means of the peel-off and breaking mechanism from the matrix. (Song, 2004)

Fracture Steel Fiber Reinforced Concrete Breakage Parameters

Fiber concrete is a composite material with different mechanical and physical properties than unreinforced concrete. One of the most important mechanical properties of fiber concrete is the energy absorption capacity. The energy absorption capacity, also called toughness, is defined as the amount of energy that the concrete undergoes under load. The area under the deformation curve is affected by the size of the test specimens, the type of the test setup and the loading speed. Many material properties such as crack resistance, ductility, impact resistance are associated with energy swallowing capacity. There are standardized toughness assessments. For example, toughness calculations according to ASTM C 1018 and JSCE SF-4 are based on one-axis bending tests. The TS 10515 standard is similar to ASTM C 1018. Therefore, the standard bending toughness of the fibrous concrete is obtained in the tests based on these standards. However, since the definition and function of the toughness is actually relative, for example, a sample geometry obtained by applying pressure to the standard cylinders or which is not determined by the standards as in this study, and the toughness to be found from the experimental studies with the loading system, can be named as relative pressure toughness or relative toughness. Toughness depends on the role of steel fibers within the concrete and is a parameter that is taken as a basis when evaluating the functionality of fibrous concretes. This feature is influenced by factors such as the fiber content of the steel fiber concrete, the rate of delicacy, fiber length, fiber geometry and loading speed and sample sizes. The increase in fiber content in the concrete, the fiber length and the growth rate of the concrete increases the toughness of the concrete. However, no function or relationship could be identified between fiber type and fiber dosage and the modulus of elasticity and compressive strength. However, the elasticity modulus and compressive strength of the concrete as well as the fracture energy is a very important material parameter. Steel fiber concrete shows a very high ductility, especially after the initial fracture load. Therefore, as the fiber ratio increases, the fracture energy increases. Many empirical definitions have been made in the literature in order to reveal such characteristics of steel fiber concretes. The most important of these is the definition of toughness index developed by Barr. The ratio of the area under the portion of the stretch-unit length change curve of the fibrous concrete to the first fracture load is defined as the Toughness Index. (Morino, 1997)

Toughness indexes have also passed the standards. The toughness indices from the experiments and calculations based on the above mentioned standards can be called the standard bending toughness indices. These indices are the numbers obtained in the load-displacement curves, divided by the area under the curve up to a defined level, divided by the area up to the first crack. In other words, toughness indices are used to define material behavior up to the selected displacement value. The first crack is defined by defining the point where the load-deflection curve is separated from the linear section for the first time. The first cracking point detected in the curve is the first crack toughness. Toughness indices are important in terms of showing the energy absorption capacity of concrete and comparing it with the witness concrete. If the toughness indexes for ASTM C 1018 are low, the energy absorption capacity after cracking is low. The toughness indexes were originally developed to explain the elastic-plastic behavior of steel fiber concretes. The low value of toughness indices indicates that the damage in post-cracking strength is large and the energy absorption rate is low. It is also possible to find the toughness indices to reach and even exceed the values of the steel fiber, such as the type, content, delicacy and matrix parameters of the fiber. The first crack point can be taken as the first point in the load-deflection curve where the load reaches the maximum value for the first time and the curve is separated from the linearity. The relative satiety indices of the double consoles were calculated in this way. At the end point of the linearity in the stress-strain curve, the first crack is formed in the material. Post-cracking is a more important task than reinforced concrete elements, especially in reinforced concrete. Coupling between the fibers after the first crack and the fibers is important in determining the properties of the composite material. The matrix fibers include slip and pull clamps depending on the type of stress transfer. In general, these two types of interconnections are related to each other. (Banthia, 2007)

Some studies in the literature on the determination of the fracture energy and relative-standard toughness of steel fiber concrete are as follows: In the concrete samples formed by the addition of steel and polypropylene fibers in different ratios, the fracture energies of the concrete with pressure and shear strengths were calculated. On the other hand, a sample geometry which can model the mixed fashion breaking performances of concrete and can be monitored on a sample at the same time, by selecting a sample geometry, four fracture surfaces were formed in different regions and the heterogeneous structure of the concrete was better expressed. The standard toughness of the concrete beams with different dosing and steel fiber ratios was found, and the relative toughness (energy absorption capacity) was obtained from the standard cylinder samples of the same concretes. The elastic modulus and relative toughness of the C20 grade concrete standard cylinder samples were determined. The relative toughness properties of standard cylinders with different steel fiber and concrete mixing ratios were found under pressure. Breaking deformation under pressure of concrete standard cylinder samples with different steel fiber ratios and subjected to different heat treatments (relative toughness) was found. Standard cylinders and pyrima samples with different fiber ratios have been found to have relative toughness (energy absorption) according to different curing environments. (Bischoff, 2003)

Conclusions

This paper introduces the mechanical properties of Steel Fiber Reinforced Concrete (SFRC), its focal points, and its applications. Amid the most recent decades unbelievable advancement have been made in solid innovation. One of the significant advances is Fiber Reinforced Concrete (FRC) which can be characterized as a composite material comprising of traditional cement fortified by the irregular dispersal of short, discontinious, and discrete fine strands of particular geometry. Not at all like ordinary strengthening steel bars, which are particularly structured and put in the ductile zone of the solid part, strands are thin, short and circulated arbitrarily all through the solid part. Among a wide range of strands which can be utilized as solid support, Steel Fibers are the most mainstream one. The execution of the Steel Fiber Reinforced Concrete (SFRC) has demonstrated a noteworthy enhancement in flexural quality and generally speaking durability analyzed against Conventional Reinforced Concrete.

REFERENCES

Baloch, S. U. (2005). Steel fiber reinforced concrete. Science Technology and Development, 21-32.

Banthia, N. (2007). Toughness enhancement in steel fiber reinforced concrete through fiber hybridization. Cement and Concrete Research, 37(9), 1366-1372.

Bischoff, P. H. (2003). Tension stiffening and cracking of steel fiber-reinforced concrete. Journal of materials in civil engineering, 15(2), 174-182.

Kim, J. (2002). Shear strength of steel fiber-reinforced concrete beams without stirrups. ACI Structural Journal, 99(4), 530-538.

Morino, K. (1997). Mechanical properties of steel fiber-reinforced, high-strength, lightweight concrete. Cement and Concrete Composites, 19(4), 307-313.

Song, P. S. (2004). Mechanical properties of high-strength steel fiber-reinforced concrete. Construction and Building Materials, 18(9), 669-673.

Soroushian, P. (1990). Distribution and orientation of fibers in steel fiber reinforced concrete. Materials Journal, 87(5), 433-439.

Thomas, J. (2007). Mechanical properties of steel fiber-reinforced concrete. Journal of materials in civil engineering, 19(5), 385-392.

Van Chanh, N. (2004). Steel fiber reinforced concrete. In Faculty of Civil Engineering Ho chi minh City university of Technology. Seminar Material, 108-116.