Development of fiber-reinforced mortar (high performance or highly deformed FRC) to exhibit metallic (or pseudo-metallic) deformation

- **to endure the deformation greater than that causing the failure of previous mortar by 200 times**
- **to limit the crack width to the micro scale even a under large deformation**
- **to establish a methodology to design the high performance FRC based on micro-fracture mechanics**

Kajima (President 梅田貞夫) has successfully developed fiber-reinforced mortar* (high performance FRC) exhibiting ductile performance under tension like steel, and thus become closer to commercialization.

A strain capacity of high performance FRC, in which high strength reinforcing fibers are 3-dimensionally dispersed in mortar, is higher than a normal mortar materials by 200 times, since the design of the high performance FRC employs a micromechanics to optimize the properties of the composite components. Thus, a high deformation capacity of a cementitious material has become realized.

Under the tensile deformation, many multiple microcracks to take higher tensile load are formed, leading to the high strain capacity. Even under the severe deformation, the crack width formed is limited to be lower than 0.1 mm, resulting in high durability.

Due to its high strain capacity, the high performance FRC can be utilized as a high performance seismic resistant material (i.e, shear panel, and so on) satisfying the seismic resistant safety regulation. In addition, we are actively working on broadening applications of the material from reduction of vibration amplitude in seismic resistant structural elements (column, beam, and so on) to the highly durable structure (mainly for infrastructures like bridges and tunnels).

[Background]

In normal concrete widely utilized as a building structure, deterioration due to the continuous load and aging is concentrated on specific parts. It results in large cracks,

* Differences between mortar and concrete: Mortar is composed of cement, sand, water, while concrete is composed of mortar and aggregates

which accelerate the deterioration of the concrete, although most other regions in the material are preserved well.

However, the large crack causes the reinforced concrete to lose its load capacity under seismic deformation. Besides, it reduces long-term durability in a direct or indirect way.

For example, seismic deformation drives formation of large cracks in concrete in a seismic resistant structure, resulting in the spalling of the steel reinforcements inside the concrete. Thus, the concrete and the steel reinforcements are not acting together to take the loads any more. This is regarded as the main reason to cause the catastrophic failure of the structure. In addition, some cracks with large width do not prevent the permeation of water and oxidative chemicals into the structure. Thus, it shortens the life-time of the structure, because it enhances the corrosion of steel reinforcement and failure of concrete. Hence, the crack width is regarded as one of the important factors to govern the durability of structure.

Previously, the method to minimize the crack width with much stronger concrete has been adopted. However, it could not achieve the material, which absorbs energy under large deformation. This motivates the development of the FRC materials with a high toughness.

[Introduction of high performance FRC]

Highly toughened FRC material forms a new crack prior to the further expansion of width of crack previously formed, leading to the formation of multiple microcracks shown in picture 1. Thus, high tensile strain is achieved by this mechanism. This is attributed to the fibers in composite, which has a high efficiency to transfer the load to the matrix.

Picture 2 shows an example of the material that endures the large deformation. Highly toughened FRC is composed of cement, water, and sand, which are the components of conventional mortar, together with poly(vinyl alcohol) (PVA) fibers (manufactured by Kuraray company: Picture 3). This PVA fiber is suitable for FRC reinforcement, in terms of extremely high fiber strength, excellent dispersability in mortar, reasonably low material cost, and so on.

In addition, features of the material are to use micro-fracture mechanics that analyzes and models the behavior of fibers dispersed in cement matrix based on experimental data. This modeling facilitates the "material design" which determines the formulation of raw materials, and thus realizing the desired tensile performance.

While the academic institute and governmental research institute had been conducting a fundamental research on a similar composite materials, **Kajima developed FRC which did not only accomplish the significant reduction of material cost but also exhibited the excellent long-term durability. Thus, the application of the FRC on the real building structure has become much closer at hand.**

[Future direction]

Highly toughened FRC with the high durability will be utilized in high performance seismic resistant structures that require high seismic resistant safety. We will also pursue the realization of highly durable structure that utilizes the high efficiency of crack width control of the highly toughened FRC. We are also investigating the marketability of pre-mix material (it becomes a complete mix once we add appropriate amount of water) to commercialize it in the near future.