THE EFFECT OF MICROCRACKING IN BRICK MASONRY ON ITS MECHANICAL BEHAVIOR

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1. ABSTRACT

It is necessary to study the microlevel failure mechanisms of brick masonry in order to improve its quality and develop a rational constitutive model to describe the brick masonry. Nonlinearity and strain-softening behavior of brick masonry have to be incorporated into efficient design. The initiation and propagation of all kinds of microcracks in brick masonry result in the weakness of physical-mechanical properties of brick masonry, which is the effect of damage to brick masonry. The failure for brick masonry results from progressive microcracks growth and is the final stage of microcracks growth, and the microcracks evolutional law has to studied in order to really describe all properties of brick masonry.

2. INTRODUCTION

It is well known that brittle and quasi-brittle material (e.g. ceramics, rock, concrete, mortar, brick and composite materials) exhibit, in loading processes, a progressive loss of stiffness (up to a limit load beyond which strain-softening take place). such mechanical behavior is commonly attributed to presence of materials defects, like flaws and voids. In a loading process, existing defects may grow and coalesce and new defects may be nucleated inducing a progressive change in the material microstructure, and damage, to which the loss of stiffness is directly related. The mechanical properties and the ultimate strength of

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engineering material, to a large degree, depend on the microdefects in their structure. This internal state of the material, as defined by the existing density, distribution, and type of microdefects, can be changed only at the expense of externally supplied energy. The distributed defects in materials and structures not only lead to crack initiation and final fracture, but also induce progressive material deterioration (material damage). Proper understanding and the mechanical description of the damage process of material brought about by the internal defects are of vital important in discussing the mechanical effects of the material deterioration on the macroscopic behavior of material, as well as in elucidating the process loading from these defects to the final fracture. The nonlinearity of the mechanical response of most engineering materials arise in general as a consequence of a specific pattern in irreversible energy dissipation, changes in their microstructure. In case of brittle solids the deviation from the elastic response is a result of the nucleation of new microcracks and the growth of existing microcracks. The microstructural change has a profound effect on the macrostructural response in quantitative and qualitative sense. The recent development of the continuum damage mechanics (CDM) seems to offer a rational framework for the establishment of methods aimed for the prediction of nonlinear response of material and structure, and the effect of microcrack initiation growth on macroscopic behavior of material and structure [1-4].

Brick masonry is used widely in civil engineering. It is a complex material consisting of brick and mortar joint, each with different properties. There is the lack of fundamental insight into the masonry behavior. The character of masonry deformation is not fully understood in microscope and macroscope. At present, the situation is at the stage of description and classification of macroscopic behavior observed. CDM has been widely used to study nonlinear response and strain-softening of concrete and rock [5-9], but no similar researches have been reported for masonry.

Masonry is considered as a two-phase material consisting of brick and mortar matrix. There are defects, like flaws and voids, in brick, and drying shrinkage in mortar will cause different microcracking. Under the loading, the microcracks will develop. Some work have been done with provision for cracking and progressive local failure [10-12]. The cracking and progressive local failure are significant cause of nonlinear behavior in masonry structure. Specially after post-peak, the cracking is the dominant cause of softening for masonry [13]. Strain-softening is a manifestation of damage. How to accurately describe the cracking is very important. Description of damage for masonry under the load is essential if the realistic behavior of the masonry is to be simulated.

In this paper, the effect of growth and propagation of microcracks in masonry on macroscopic behavior is studied.

3. MICROCRACKS IN BRICK AND MORTAR

There exist microcracks in mortar and brick-mortar bond interface due to during shrinkage, and the presence of the microaggregate particles (sand) [14], as shown in Fig. 1. There are voids, flaws and inclusions in brick, as shown in Fig. 2. Even prior to loading. The cracks have been observed. The microcracks begin to grow under
increasing loading. Initiation, growth and propagation of the microcracks effect on the macroscopic behavior of masonry under the loading.

Fig.1 Microcracks in Mortar  Fig.2 Voids, Flaws and Inclusions in brick

4. CHARACTER OF MASONRY DEFORMATION

Stack-bonded prisms were tested to obtain descending branch of load-deformation, as illustrated in Fig.3. Load-deformation curve was shown in Fig.4.
According to law of microcracking in brick masonry, the macroscopic mechanical behavior of masonry can be summarized as: (1) approximately elastic stage, (2) non-elastic stage, (3) strain-softening stage.

4.1 Approximately Elastic Stage

At the early stage of loading, bed joint and brick-mortar bond surface is densified, and microcracks in mortar generally appear to go around microaggregates(sand), parallel to loading direction. Microcracks in brick unit also appear. Up to about 40% of the ultimate load $P_{ult}$, there is very little extension of these microcracks, no macrocracks are observed. Beyond 0.4 $P_{ult}$, microcracks in brick unit independently grow under increasing load. At about 50%-70% of the ultimate load $P_{ult}$, macrocracks in brick appear, which can be observed on the surface. This is attributed to interaction of brick and bed joint. Usually, Young’s modulus $E_j$ of mortar is significantly lower than Young’s modulus $E_b$ of the brick, while Poisson’s ratio $\nu_j$ of the mortar joint is higher than Poisson’s ratio $\nu_b$ of the brick. This departure in elastic properties of the constituents sets the overall behavior of the composite. Horizontal compressive stresses form in the bed joint and horizontal tensile stresses in the brick, as shown in Fig. 5. At this stage, the cracks are stable. If loading stops, readings in dial gauge extensometer kept constant. The stress-strain curve is almost linear, corresponding OA portion load-deformation curve.

![Fig. 5 Horizontal Stresses in Brick and Mortar due to Compression](image)

4.2 Non-Elastic Stage

Beyond 0.5-0.7$P_{ult}$, the cracks in brick unit increase in length and width, and new microcracks are formed. Cracks in bed joint are formed due to cracking in brick. The cracks in mortar and brick join together. Microcracks in specimen begin to form a much more extensive network. By this time, cracks are unstable. Even if load fail increasing, cracks still grow in parallel to loading. The stress-strain curve becomes increasingly nonlinear. This non-linearity is due largely to the nonlinear deformation characteristic of bed joint and progressive microcracking(or the result of a large number of microscopic brittle failure). This stage corresponds to AB portion of load-deformation curve.
4.3 Strain-Softening Stage

After peak-load was reached, cracks in brick units grow to be extensive due to interaction of brick and bed joint. Cracks form between macrocracks, as shown in Fig.6. Cracks are not disorderly, but parallel to loading. However, there are relative little cracks in bed joint, which is formed due to cracking of brick unit. The mortar is in compression. Brick's lateral confinement makes mortar stronger and more ductile, and delays or even prevent softening and macrocrack formation. The specimen occurs lateral expansion and bulge. After specimen failed, brick unit is divided into a number of triangular or conical pieces. In mortar compressive traces were observed, as shown in Fig.7. At this stage, a gradual decrease of stress at an increasing strain, called strain-softening, is observed.

Fig.6 Simulation of Cracking in Brick Unit

Masonry is a heterogeneous material composing brick units and mortar joints. Internal stresses and cracks are already present before loading. This causes that a progressive crack growth is found in masonry specimen when it is subjected to a progressive deformation. Especially cracking in brick unit play an important role in this process of crack growth. After post-peak load, progressive cracking in brick unit finally results in softening of the specimen, and is a dominant cause of softening of brick masonry, softening of mortar is a secondary factor. Softening of brick masonry loaded in compression is probably also accompanied by
Localization. Crack growth results in softening and localization of cracking, which is the most salient feature connected to softening. Localization of cracking means that all further cracking, but also deformation, concentrate in a small zone. The descending branch of load-deformation curve depends on gauge length and position of deformation measurement, as shown in Fig. 8.

![Fig. 8 Effect of Gauge Length and Position of Deformation Measurement on Descending Branch](image)

At the strain-softening stage, deformation concentrates in local position of specimen. Cracking fails to grow in other position of specimen. So strain-softening and failure of specimen almost are correlated with the cracking, mechanical properties of pieces divided by vertical cracks have little influence on stress-strain curve.

Damage is already found for a low load. During further deformation the damage zones grow At 50%-70% of peak load the damage zones start to extend. The damage is still distributed. At peak load the growth of damage accelerates. The localization of damage starts from this moment on. Initial elastic modulus of brick masonry vary due to the damage. Initial elastic modulus measurements of brick masonry were made by drawing tangents to the loading portion of each cycle at a stress of 5N/mm². The variation of initial elastic modulus with deformation increases is shown in Fig. 9. There is a progressive reduction in initial elastic modulus as the previous applied deformation increases. The reduction is little at the outset, but the rate of change becomes greatest in the region of the load-displacement curve following the peak-load. This clearly corresponds to the quite rapid cracking after the peak load.

![Fig. 9 Change in Initial Modulus with Deformation](image)
Pre-peak nonlinear behavior and post-peak softening is a continuous process. The cracking starts as distributed microcracking. The microcracks are stable, which means that they grow only when the load is increased. Around peak load, an acceleration of cracking takes place and the formation of macrocracks starts. The macrocracks are unstable, which means that the load has to decrease to avoid an uncontrolled growth.

During microcrack growth, theory of the homogeneous continuum is still applicable to masonry. When macrocracks start to grow, the continuum theory is no longer applicable. The definitions of strain and stress are lost. The cracks have to be taken into account as discontinuities which, together with the continuum, determine the behavior of the structure. Softening is a combined response of a local and continuous process. The local process is governed by fracture mechanics, which describes the behavior of cracks. The structural response can only be analyzed by making assumptions as to the local and the continuum components of the behavior. Micromechanical models are a powerful tool for analyzing softening of masonry, softening must be introduced at microlevel. Softening is closely interrelated progressive cracking.

5. CONCLUSION

The initiation and growth of microcracks in brick masonry effect on its macroscopic behavior. Specially after post-peak load, cracking in brick unit is a dominant cause of strain-softening of brick masonry due to interaction of brick and bed joint. This mechanisms of softening of brick masonry is a main character of brick masonry distinguished from other materials such as rock, concrete, etc. The process of failure in masonry in uniaxial compression is continuous and begins at very low load. Softening of brick masonry is a manifestation of damage. Microstructural changes in brick and mortar loaded are taken into account in order to really describe all properties of brick masonry. Bricks and mortar joints are modeled separately with individual and different properties with provision for damage, allowing local nonlinear behavior and progressive cracking to be simulated.

REFERENCES