FRACTURE ENERGY AND MECHANICAL BEHAVIOUR OF CLAY ELEMENTS

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Clay blocks are extensively used in civil constructions as part of beam-block floor systems and their toughness and mechanical characteristics assume an important role in the structural behaviour. A large experimental campaign aimed to the characterization of different basic clay mixtures was then programmed on ten series of specimens cut from blocks of ordinary production, representative of ten different geographical origins.

Both classical strength parameters and toughness are strongly influenced by the clay mixture composition and the results are discussed in the paper.

INTRODUCTION

In beam-block concrete floors used in civil constructions both concrete and clay blocks can partecipate to strength resistance of the whole structure: both components should guarantee a sufficient deformability and a minimum of resistance (compressive strength) to be considered collaborating with the prefabricated or cast in situ concrete beams, in the structural behaviour of the floor.

Clay blocks usually show a compressive and tensile strength, as well as an ultimate tensile elongation, higher than that shown by concrete blocks. On the other hand the material that constitute clay blocks can present reduced fracture toughness characteristics, always compared to those shown by concrete components. All these aspects assume a decisive role in the structural behaviour when imposed deformations depending on environmental and time-depending effects act in connection with the load effects in the floor system.

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In the last years more and more attention has been devoted for improving the knowledge about the mechanical and toughness characteristics of clay blocks, with particular attention to the influence of the different basic clay mixtures on the constitutive laws and fracture energy of the final product (1), (2), (3).

In particular, to determine fracture energy values and the values of the parameters that govern the fracture phenomenon of several materials used in civil engineering, different experimental methods were adopted. Within the large experimental campaign of tests aimed to the characterization of different basic clay mixtures, whose results are discussed in this report, the test method adopted was based on that well known used for concrete specimens (4) and it was considered sufficiently appropriate for clay materials on the basis of previous applications, in which two of these materials were already extensively studied (5).

In the following will be illustrated the experimental programme and the results obtained, concerning mechanical and toughness characteristics of the materials. A comparison is then made with the correspondent values shown by a normal strength concrete.

EXPERIMENTAL PROGRAMME

The whole programme, carried out at the Department of Structural Engineering of Politecnico di Torino, made provision for laboratory tests, aimed to the determination of compressive and tensile strength, modulus of elasticity, toughness characteristics and fracture energy of specimens cut from clay blocks of ordinary production, manufactured with ten different clay mixtures, representative of the Italian situation.

For fracture energy determination the three point bending tests were performed in crack mouth opening displacement (CMOD) controlled conditions by a servocontrolled testing machine. The 109 useful results obtained concern ten series of specimens of ten different materials (marked by the letters from A to H), with total length equal to 240 mm (span length L = 230 mm), depth h=40 mm and thickness b varying from 6 to 8 mm (according to the actual thickness of ribs and webs of the blocks from which the specimens were taken). For each series of specimens three nominal notch length to specimen depth ratio a/h were taken into account: 0.1, 0.3 and 0.5. A number of useful results variable from three to five were obtained for each notch depth and clay type.

During the tests, performed according to the scheme given by RILEM Recommendation for concrete specimens (see Figure 1) by using a special apparatus specifically prepared, high sensitivity contactless transducers were employed for measuring deflections at midspan and at supports with a maximum error of 1 μm. Load–deflection curves were then obtained, at midspan, after deduction of the settlement at supports.

The Young's modulus was programmed to be measured by means of compression tests on four specimens for each material. The thickness of the specimens, always obtained directly from blocks of ordinary production, was variable from 6 to 8 mm, while the other dimension of the cross section was 20 mm and the length, along with the load was applied, was 60 mm. Two strain gauges were located on the two opposite faces of the specimens, in the direction of the applied load, and the mean longitudinal deformation was recorded versus the load. The ultimate load (at compression failure) was taken into account to obtain the compressive strength f_c of the materials.

The tensile (flexural) strength f_t of the materials was obtained by three point bending tests, on specimens having the same cross section of those used for Young's modulus determination and span equal to 100 mm (in this case the depth of the specimens was coincident with the thickness). Five specimens for each material were tested. The tensile (direct) strength results are not available yet.

EXPERIMENTAL RESULTS AND DISCUSSION

The results (both classical parameters and fracture energy values) were strongly dependent by the clay mixture composition. The minimum of tensile strength and compressive strength (obtained up to now) was shown by material G with values respectively equal to 42 N/mm^2 and to 8.5 N/mm^2. The material G also showed the minimum value of Young's modulus *E*. The ratio between the maximum and minimum value of compressive and tensile strength, as well as the modulus of elasticity, was just greater than 2.5.

The value of fracture energy, G_f, were calculated on the basis of the ratio between the area under the experimental load versus deflection curves, taking into account the weight of the specimen and the weight of the devices used during the tests, and the area of the ligament given by $b \cdot (h-a)$. The distribution of the results (ordered in decreasing way from material B to material D) is plotted in Figure 2 where clearly appears the regular variation of values from the minimum of 20.8 N/m (material D) to 29.8 N/m (material F), while material B shows a decidedly higher value of 39.6 N/m.

Regarding the load–midspan deflection diagrams obtained by three point bending tests on the notched specimens, attention was also given to the length of the softening part of the curve that indicates how the bridging and other non linear phenomena postpone the complete separation in two parts of the specimen after the peak load has been reached. The ratio β between this quantity and the deflection at peak load (elastic part of the load–deflection curve) can be regarded as an index of toughness of the material. The distribution of these values is again shown, by comparison with the correspondent distribution of fracture energy values, in Figure 2. Although it is easy to understand that, experimentally, the tail's length of the curves can show high variability for similar specimens (in particular for very tough materials) while its influence on the fracture energy value is practically negligible, the index of toughness β shows the same trend observed for the fracture energy distribution, for the whole series of materials.

Classical mechanical characteristics, that is compressive strength, tensile (flexural) strength and modulus of elasticity have a decreasing distribution of values from materials I and C (that have almost the same characteristics) to material G. On the contrary, fracture energy shows comparable values and slightly increasing trend (maximum variation 30%) for seven materials (I, C, H, A, E, L, D), while is decidedly higher for the remaining three materials, B (absolute maximum), F and G. Figure 3 shows the distribution of tensile strength and fracture energy values (the former ordered decreasingly), for the ten materials. It is then possible to affirm that the values of fracture energy and those of strength (compressive and tensile), have opposite trend.

The snap–back was observed in eight materials, at least for the notch length to specimen depth ratio a/h equal to 0.1; nearly always the phenomenon was very evident. Only the two materials F and G did not show positive slope in the load–midspan deflection curve after the peak load: these are the materials that showed the higher fracture energy. In Figure 4 is reported the experimental load–midspan deflection curve (thick line) and the theoretical curve given by linear elastic fracture mechanics (thin line), for a specimen type A with nominal a/h=0.1.

The K_{IC} values (critical stress intensity factor) were obtained from the relationship $\sqrt{G_f \cdot E}$ and showed a distribution similar to that obtained for the tensile strength distribution. In this way the distribution of K_{IC} and G_f values show the opposite trend already observed in Figure 3 where the tensile strength of the material is reported instead of the critical stress intensity factor. As a consequence the three materials B, F and G, that have the higher values of fracture energy (energy toughness parameter) show the lower values of K_{IC} (stress toughness parameter). For these materials the linear elastic fracture mechanics is clearly not applicable.

Another important parameter that characterize the structural behaviour of clay blocks is the deformation $\varepsilon_u = f_t/E$ at tensile maximum strength (peak load) of the material, that was found variable between $0.6 \cdot 10^{-3}$ for material L and $0.9 \cdot 10^{-3}$ for material A. These values are relatively high because clay blocks concurrently show high values of tensile strength and relatively low values of modulus of elasticity. The values of ultimate deformation are then higher than those usually shown by normal strength concrete, while fracture energy is decidedly lower.

CONCLUSIONS

All the mechanical and toughness parameters were strongly influenced by the clay mixture composition. The values of fracture energy, G_f, varied from 20.8 N/m to 29.8 N/m for nine out of ten materials; only one material showed a decidedly higher value of 39.6 N/m. The snap–back was observed, after the peak load, in eight out of ten materials, at least for the lower initial notch length to specimen depth ratio. The phenomenon was nearly always very evident.

The ultimate (tensile) deformation of the materials varied between $0.6 \cdot 10^{-3}$ and $0.9 \cdot 10^{-3}$. Compressive strength, tensile strength and Young's modulus showed similar variations, with opposite trend respect to that found for fracture energy.

By comparison with the behaviour of normal strength concrete it is possible to affirm that clay materials have lower fracture toughness (about 1/4 as mean value) but higher ultimate tensile deformation. Compressive and tensile strength are decidedly higher for clay materials while the modulus of elasticity (as mean value) is slightly higher in concrete.

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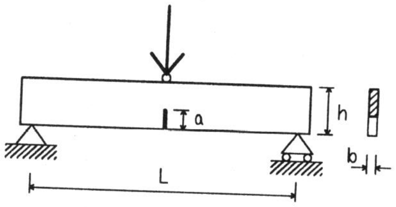

Figure 1 Testing scheme

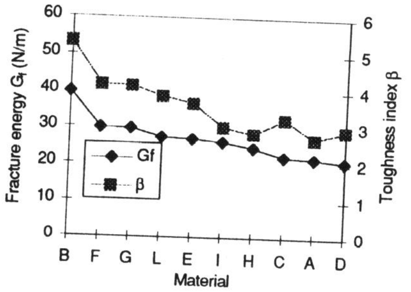

Figure 2 Fracture energy and toughness index distribution

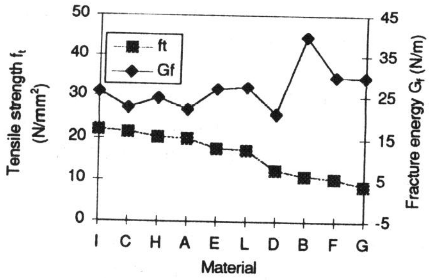

Figure 3 Tensile strength and fracture energy distribution

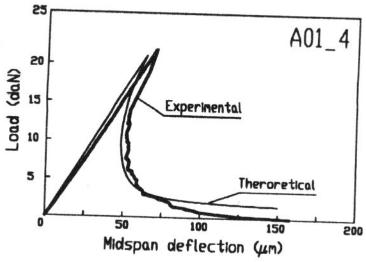

Figure 4 Load versus midspan deflection for specimen A01_4 (a/h=0.1)