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Archives of Civil and Mechanical Engineering

Original Research Article

A new lightweight masonry block: Thermal and mechanical performance

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ARTICLE INFO

Article history:
Received 23 April 2013
Accepted 15 August 2013
Available online 24 August 2013

Keywords:
Large block systems
Thermal performance
Mechanical performance
Experimental characterization

ABSTRACT

The concerns with masonry building envelope performance, particularly thermal efficiency, are causing major changes in masonry solutions, mainly in south European countries, where traditionally the mild winter climate justified the use of high thermal masonry wall performance. The new European Directives regulations require different solutions. This paper describes the development a new masonry system, based on lightweight concrete units, intended for construction of large single leaf external walls without thermal insulation materials. A detailed analysis and optimization has been performed by FEM, under thermal point of view. This work was followed by a set of experimental tests in order to characterize the mechanical behavior of single units and masonry specimens. The concerns with productivity and ergonomics are also considered according their importance to the solution cost.

1. Introduction

Masonry is a common component with low maintenance and good durability. Several new materials and modern building masonry technologies are now available in the building marketplace. The walls that make up the envelope of buildings are one of the features needing improvements, because, despite their economic and functional importance, they are the building elements in which most defects are noticeable. On the other hand the concerns associated with thermal comfort and energy saving are putting pressure on construction in the sense of greater attention towards problems that in the past were given less consideration. To answer these new challenges two ways are mainly available: to add higher thickness of thermal insulation in association with current masonry units walls, or to change masonry units, combining improved thermal insulation with enough mechanical resistance. The use of thick single-leaf envelope walls can be an interesting alternative to cavity walls in some Mediterranean countries.

Today there is a growing emphasis on efficiency in terms of energy, esthetics and the quality of interior spaces, which lead to higher demands in the building enclosures. In order to have a high and distinguishing presence in buildings

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1644-9665/$ - see front matter
http://dx.doi.org/10.1016/j.acme.2013.08.003

masonry would need to evolve, thus ensuring more functions and always at a competitive cost.

Recent studies looking for energy savings in buildings have been conducted on the manufacture of lightweight bricks and masonry blocks using high heat resistant materials [1–11]. The use of masonry blocks made from expanded clay aggregates is increasing and is acceptable since material and construction techniques used lead to a satisfactory structural behavior [1,2,4,5,8]. Concrete expanded clay blocks blend good noise insulation, high levels of heat insulation and comfort (thermal inertia) due to the volume of air voids. Furthermore concrete blocks are inert, non-toxic and do not burn. Unfortunately, compressive strengths of lightweight concretes are lower than those of normal density concretes, and the low compressive strength reduces the load that can be carried by walls. On the other hand, the cost of transport and laying decreases with lower densities, leading to a reduction in building costs.

The development of a new block needs to take into account the following aspects: material, overall density, thermal and mechanical requirements, geometry, topology and laying requirements, production and technological constraints.

Without minimizing the requirements related to security, stability and durability of the buildings, a search for the optimal topology of lightweight concrete masonry units according to normal thermal demands is presented.

Masonry systems are a set of pieces with different topologies and dimensions, which allow various applications and details to be carried out, seeing the wall as a constructive system for which, in addition to the standard units, individual pieces are also developed to solve all situations. Masonry is a composite structure characterized by a regular arrangement of blocks or bricks that are periodically distributed and joined with mortar. Masonry is anisotropic due to the presence of horizontal and vertical mortar joints and presents orthotropic strength and softening characteristics, which depend not only on the properties of masonry constituent materials but also on the workmanship.

As compressive strengths of lightweight concretes are lower than those of normal density concretes, experimental tests of single blocks and masonry specimens were also performed according to European Standards, in order to determine the compressive strength in the direction normal to the bed joints.

2. Masonry performance

Nowadays there is a world-wide trend towards energy saving and efficiency in all sectors to promote financial savings and health, and protect the environment. To ensure that masonry is effectively able to meet all requirements, it is necessary to make changes to the masonry units and their laying process. It is possible to intervene in this optimization process in the following aspects:

– raw material of the units;
– geometry of the units;
– incorporation of other products in these units;
– mortar laying.

Some of these aspects give rise to contradictory effects; for example the high level of heat insulation leads to a generally low level of mechanical resistance. The materials of the "new generation" have a multifunctional nature and can be used in confined or reinforced masonry, or only as simple infill, fulfilling both functions at the same time. Normally these walls are externally covered with render to be painted and generally they demonstrate good performances, including the necessary watertightness. Building with this type of basic component can avoid, particularly in the countries of southern Europe, the use of thermal insulation in the vertical enclosure.

2.1. *Masonry thermal optimization*

Optimization techniques supported in numerical simulations can be useful in industrial terms, as they enable an in-depth study of the characteristics of the products, avoiding tests of production materials, which are costly in terms of both time and material costs. These simulation techniques can also help to eliminate potential design defects. For the simulation of the thermal behavior of masonry walls the method of finite elements can be used.

In the particular case of topological optimization of masonry units, the objective is to minimize the overall coefficient of heat transfer of the wall, taking into account the constraints of technological nature associated with the industrial process, walls behavior and construction [4]. Given a design vector $\mathbf{b} = \{b_1, \ldots, b_D\} \in R^D$ with the process parameters referred above, the optimization problem can be defined as

$$\text{minimize } \Pi(\mathbf{b}) \tag{1}$$

subject to side constraints $b_{D^-} \le b_D \le b_{D^+},\ d = 1, \ldots, D$ and to the state equations of the thermal problem.

The main factors that influence the thermal performance of units and masonry are the positioning of the holes, the number of rows of voids and their relative position, size, shape and thermal characteristics of the voids, the geometrical characteristics of the mortar joints and the thermal conductivity of the materials.

Since the optimization problem has an associated discrete domain, a Genetic Algorithm (GA) is adopted to obtain the optimal solution. The GA method is a stochastic search method that borrows the operations and themes from natural evolution. After identifying the design variables and their suitable search domains there exists a multitude of possible solutions that form a solution space. In a GA, a highly effective search of the solution space is performed, allowing a population of strings representing possible solutions to evolve through basic genetic operators. The developed algorithm considers the codification of the data, the definition of the fitness function and a population evolution based on an elitist strategy. The implemented GA [12–14] is based on four operators: selection, crossover, elimination/substitution and mutation, supported by an elitist strategy that always preserves a core of best individuals of the population. The flow diagram of the optimization algorithm is shown in Fig. 1.

The optimization problem considers an objective function that measures the masonry wall transmittance value, subjected