



ANALYSIS OF CRACKING OF CELLULAR CONCRETE BLOCK (THERMOSTONE)

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ABSTRACT

This research deals with a problem that exists during manufacturing of thermostone blocks which are produced in a company for insulation building material.

Micro and macro cracks are some of those problems which reduce the resistance to fracture under loads, or causing damage to the product during manufacturing processes.

The research applies practical -theoretical method to determine the mechanism of fracture, depending on taking two images, one is a stereo microscope with suitable magnification, so that all different phases can be seen as possible, the second one is a video image to show pores and cracks.

A numerical solution (finite element method) was applied on the images. Chemical composition and percentage of elements and their effect on fracture behavior have been studied also.

Keywords: Finite Element , Cracking Analysis , Thermostone

الخلاصة:

هذا البحث يعالج مشكلة تعاني منها مادة كتل الثرمستون المنتجة في احد المعامل المحلية لتصنيع مواد البناء العازلة ، وهي وجود شقوق ظاهرية ومجهريه في المنتج تؤدي إلى انخفاض مقاومة الكسر ، او حدوث تلف داخل المنتج أثناء عملية التصنيع .

يتضمن البحث دراسة الاسباب المؤدية الى ذلك وكيفية المعالجة بالاضافة الى استخدام اسلوب عملي - نظري لتحديد الشقوق وميكانيكية الكسر تعتمد على اخذ صورتين احدهما مجهرية (Stereo microscope) بتكبير مناسب يظهر اغلب الأطوار، والاخرى صورة فيديو (Video image) بتكبير يظهر الشقوق والفجوات، وتطبيق اسلوب حل عددي (finite element) ، مع مراعاة التركيب الكيميائي للمادة ونسب المواد الداخلة فيها وتأثيرها على مقاومة الكسر.

INTRODUCTION

The main role of the existence of pores in thermostone blocks is to get high sound and thermal insulation. On the other hand these pores may reduce compressive strength of the blocks or even cause damage of the product during manufacturing process.

This damage causes significant losses to the manufacturers and uses because it is too difficult to make use or recycling of the damaged product.

The present research aims to study the effect of these pores on the mechanism of fracture besides other factors such as the micro cracks and the reason of their appearance, and the percentages of the added row materials during thermostone block production specially the (limestone).

There are several methods to study the mechanism of failure and to estimate or guess the cracks in the structure which have been used by many researchers.

These methods could be classified as theoretical or practical applications or both of them.

(P.E. Stutzman, et al 2001) used a method to determine pattern of cracks in concrete using video image and finite element method. They determined many reasons of cracks and they introduced a new method to study the mechanism of damage.

(Van Gemert et al 2003) used porous concrete to obtain noise reduction; they added several materials to the fresh structure to obtain sufficient strength. They established a relation between the micro and macro – structures.

(Van Gemert D et al 2002), studied the nature of stress – strain behavior of block, stone, and cracks repair. They showed that not only the nature of stone or block can be account for the type of deterioration of the masonry, but also the structural built up will play an important role.

(Justness H et al, 2002), study the pores in concrete and their effect on compressive strength, and they added accelerators through the process of production to increase compressive strength and reduce cracking.

The present work uses both the theoretical and practical methods and each one will support the other.

A video image was taken so that pores and macro –cracks are as clear as possible, and a finite element solution was applied with the following assumptions (Chandrupatla et al 1997) :

- 1- Linear elastic solution.
- 2- Homogenous , isotropic material
- 3- Free boundary conditions on the edges of pores
- 4- Every pore represents an element.

A stereo microscope image was also taken so that phases are clear, and then a finite element solution was applied with the following assumptions: (Chandrupatla et al 1997)

- 1- Linear elastic solution
- 2- Non – homogenous material (every phase has individual properties)
- 3- Top of the surface is free boundary condition.

The present work makes use of combining both image and finite element techniques to study the mechanism of fracture.

The program used for this analysis was a 2-dimensional elastic finite element, using a plane strain case, and the differential of integral form of stress-strain relationships.

The practical side of the research includes making a number of samples with different ratios of limestone, then testing compressive strength to study the effect of this material on cracking and strength of samples.

A comparison was made between cracks which getting from (F E M) and those found in image (virtual cracks).

MATERIALS AND METHODS

Materials

Table (1) shows the ratios of different components of thermostone before and after manufacturing.

Images and Finite Element Method.

The process used to prepare the sample for imaging must not introduce any damage or new cracks.

Samples of thermo-stone with dimensions (100×100 ×100) mm as shown in **Fig.1(a)**, were made with different ratios of limestone CaCO₃ Table (2), then images for these samples were taken. Finally a compression test was applied on these

samples after (30)day from manufacturing using compression machine (Feinmess-Manometer 200 KN) as shown in **Fig. 1(b)** .

A comparison was made between these samples to know the effect of limestone ratio on strength of thermostone.

For micro cracks, images were captured by a stereo microscope. For macro-crack a video camera was completely suitable in away that pores and macro-cracks can be distinguished.

Fig.2 shows a video image of thermostone sample. The sample shown is taken near the top of the surface where the pores and cracks are obviously seen. These cracks have a tendency to start from the edges of pores or near by.

The image will be subdivided in away that every pore represents an element in the numerical solution. A free boundary conditions are made at nodes on the cracks or pore edges.

It is obvious that there are fine cracks in the matrix phase which is the alkali reactive and other phases of thermostone (Van Gemert et al 2004).

Here material is considered as a non-homogenous and the properties of each phase is taken alone (each phase has its own elastic properties).

Then a numerical solution was applied, the finite element method is a simple and efficient solution, assuming that the nodal point displacement of finite element mesh is completely specifies the displacement in the body.

Since thickness of the region of image is large compare with other dimensions, a plane strain case was applied, using 2-D finite element solution.

Relationships between stress and strain for this case are (Timoshenko 1970) :

$$\varepsilon_{xx} = \frac{1}{E}(\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})) \quad (1)$$

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})) \quad (2)$$

$$\varepsilon_{xy} = \frac{2(1+\nu)}{E}\sigma_{xy} \quad (3)$$

Then stress matrix (matrix of properties) [D] can be obtained from the above equations.

Rearranging eqns (1), (2) and (3) by writing them in term of matrix notation, the elastic relation between stress and strain can be written as:

$$\{\sigma\} = [D]\{\varepsilon\} \quad (4)$$

Strain matrix [B] is obtained from the following eqns (Timoshenko 1970) :

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} \quad (5)$$

$$\varepsilon_{yy} = \frac{\partial v}{\partial y} \quad (6)$$

$$\varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \quad (7)$$

Then strain – displacement is written in term of matrix notation as:

$$\{\varepsilon\} = [B]\{\delta\} \quad (8)$$

For structural applications, the governing equilibrium eqns. can be obtained by minimizing the total potential energy of the system (chandrupatla et al 1997) as :

$$\frac{\partial M}{\partial [\delta^e]^T} = 0 = \int_{ve} B^T DB dv \{\delta^e\} + \int_{ve} N^T F_v dv + \int_{ve} N^T F_s ds \quad (9)$$

F_v : is the body force per unit volume (The compressive load applied on the sample till damage).

F_s : is the load of surface traction.

Solving eqn. (9) gives the values of displacement for all nodes in the structure of interest, then stresses can be obtained by solving eqn. (8) and eqn.(4).

Fig. 4 shows the finite element mesh for video image case of thermostone (**Fig. 2**).The mesh was divided into elements whereas most pores are located at edges of these elements (i.e. nodes are at the edges of pores).

A free boundary conditions are represented near pores, as no adjacent material is there.

Fig. 5 shows the finite element mesh for stereo microscope image (**Fig. 3**).The top of the surface is represented as a free boundary condition in the finite element analysis.

In both cases of **Fig. 4** and **Fig. 5** the bottom of thermostone is a fixed, zero-displacement boundary condition (Hinton, Owen 1997). The edges of thermostone are away from the location where the sample's images were taken, the material can then be surrounded by an effective material (a material having the same elastic properties as the whole sample).

RESULTS AND DISCUSSION

From the finite element analysis for case of **Fig. 2**, it can be seen that cracks could occur at the edges of pores where the stresses are greatest. This result agrees with that reported by Mura (Mura 1987).

In case of sterio-microscope image, the stresses are greatest in the matrix phase of thermostone , this means that cracks could occur in this region more than in limestone phase , The same result had been noted by (Stuzman 2001).

Cracking occurs due to the formation of microcracks, these microcracks are intercepted and deflected by the tiny particles of limestone and prevent these cracks from growing together into larger cracks that can cause thermostone block to fail under loads smaller than the designed load .

Also limestone has the ability to react with silica to form complex calcium silica that binds thermostone and provides high dimensional stability and strength as in the following reaction: (Ahmed et al 2003) .



Table2 shows the results of compressive strength test of thermostone with different ratios of limestone.

According to the above results, the increasing in limestone ratio in the mix of thermostone will improve compressive strength and reduces cracking.

It can be seen from this table that the highest increase in compressive strength occurred when the percentage of limestone was 4%.

However, Iraqi specification (No.1441/2000) for Cellular Concrete Blocks (Thermostone) require a compressive strength not less than 20 KN (National Center For Construction April 2001).

Fig. 6 shows a damaged sample of (100×100 ×100) mm under 23.7 KN loads for 4% limestone ratio.

Under load, nodes near cracks move from their sites, but not freely, because phases around them act as restrains. This fact is represented by finite element method by selecting the suitable boundary conditions.

Fixed boundary conditions in the bottom, lead to the fact that total stress after equilibration will be close to zero. This small value, however, is made up of positive and negative contributions from different phases of **Fig. 3**, so that any given region in the image could be under large stress

The principal stresses and their orientation were calculated from the average stresses in each element, using simple elasticity theory as shown in Table (3).

The magnitude and direction of largest stress in the elements is very important. Cracks generally propagate perpendicularly to the direction of stresses (Bozat et al 1998), so that the directions of stresses are important.

To represent the magnitude and direction of stresses in an image, line segments are used to represent the stress field (Bozat et al 1998).The length of line segment represents the magnitude and the direction indicates the direction of the maximum stress in the element. Each line segment is shifted by 90 degree to show the direction of the crack which is created by the stress.

Fig. 7 shows line segments which represent cracks of video image.

Fig. 8 show line segments which represent crack of stereo microscope.

By this mechanism, cracks can be seen and compared simply with true cracks in the original image .It was noted that a bout 70% of crack resulted from the theoretical method (finite element method) coincide with those occurred in original images.

Recommendations for further work

- 1-Applying finite element techniques in 3-D, using x-ray images.
- 2- Using the viscoelastic solution through the stages of manufacturing due to the viscoelastic properties that material have before drying and burning.

Table1* : Components of Thermostone

Component	Chemical Characters	Ratio %	
		Before Manufacturing	After burning (200-250) •for 14hr
Sand	SiO ₂	25.3%	
Calcium Oxide	CaO	3%	5%
Gypsum	CaSO ₄ . $\frac{1}{2}$ H ₂ O	9%	15%
Ordinary Portland Cement	(CaO)/3(SiO ₂)+1.2(Al ₂ O ₃) +0.65(Fe ₂ O ₃)	20.2%	33.33%
Aluminums' Powder	Al	0.04%	Goes to vanish
Water	H ₂ O	40.38	1.67%
Clay(as impurities)	Kaolinite and Oxides	Less than (2-3)%	Less than 2%

* Information in the table are practical and taken from a Company for insulation materials.

Table2: The relation between free limestone ratio and ultimate compressive load .

ρ kg/m ³	Porosity(P) %	The added amounts of limestone ratio%	Ultimate compressive load(KN) to damage A sample of (100 × 100 × 100) mm
540	56.8	1%	20
543	56.56	2%	21.5
557	55.44	3%	22.3
563	54.96	4%	23.7
568	54.56	5%	23.4
575	54	6%	23.1

Table 3: The Magnitude of Average Stresses.

Element No.	Stress (Pas.) in Macro-crack Image	Stress (Pas.) in Micro-crack Image
1	300	50
2	300	50
3	300	50
5	300	50
10	300	50
15	300	50
20	450	0
25	350	0
30	300	75
35	300	0
40	400	100
45	500	100
50	350	0



(a)



(b)

Fig. 1: Sample of thermestone (100 × 100 × 100) mm and the compression machine.

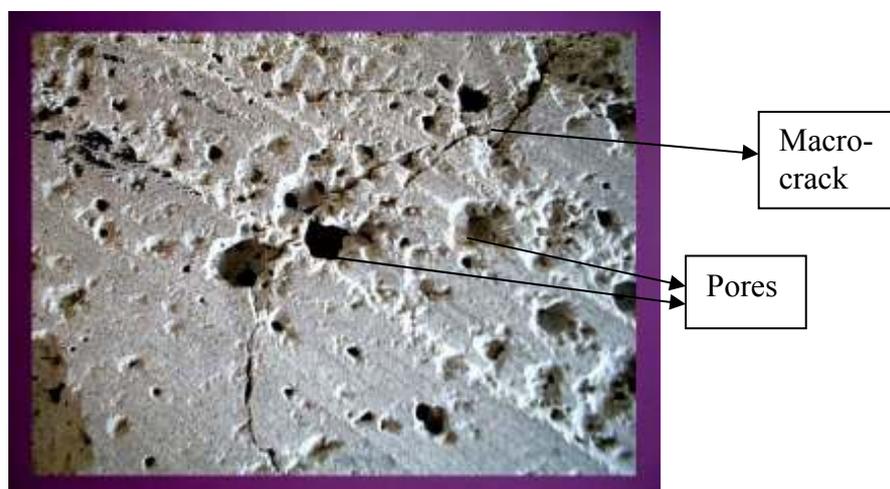


Fig. 2: A video image of thermestone (ratio of 5% CaCO₃)

Magnified by 5 times

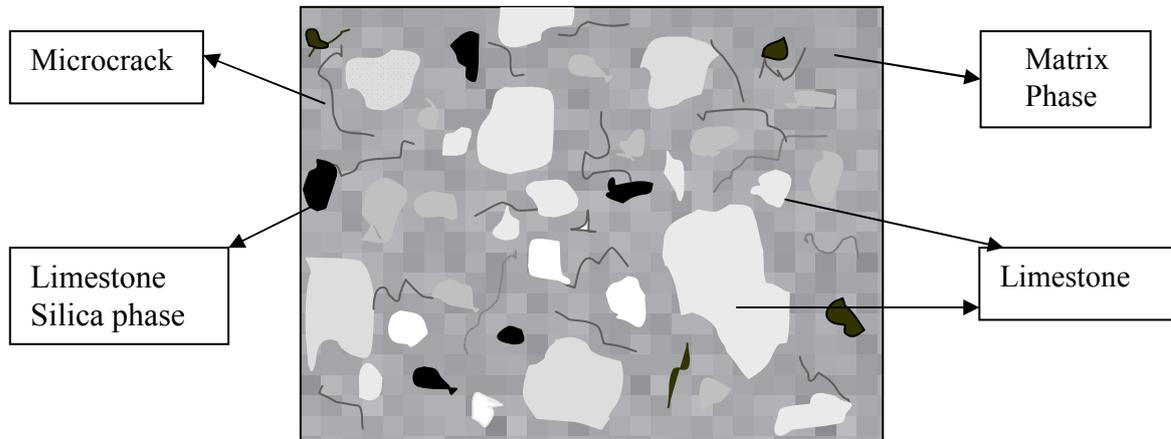


Fig. 3: Stereo microscope image of thermostone (magnification field $\times 750$)



Fig4: Finite element mesh for video image (4-node element)

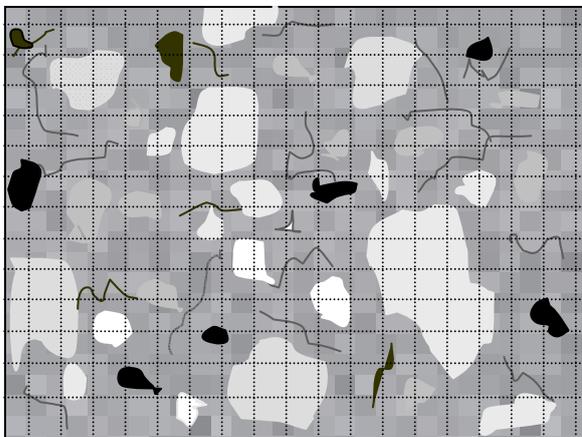


Fig5: Finite element mesh for microscopic



Fig. 6: Damaged sample (100x)

image (4-node element)

100x100) mm of 4% limestone

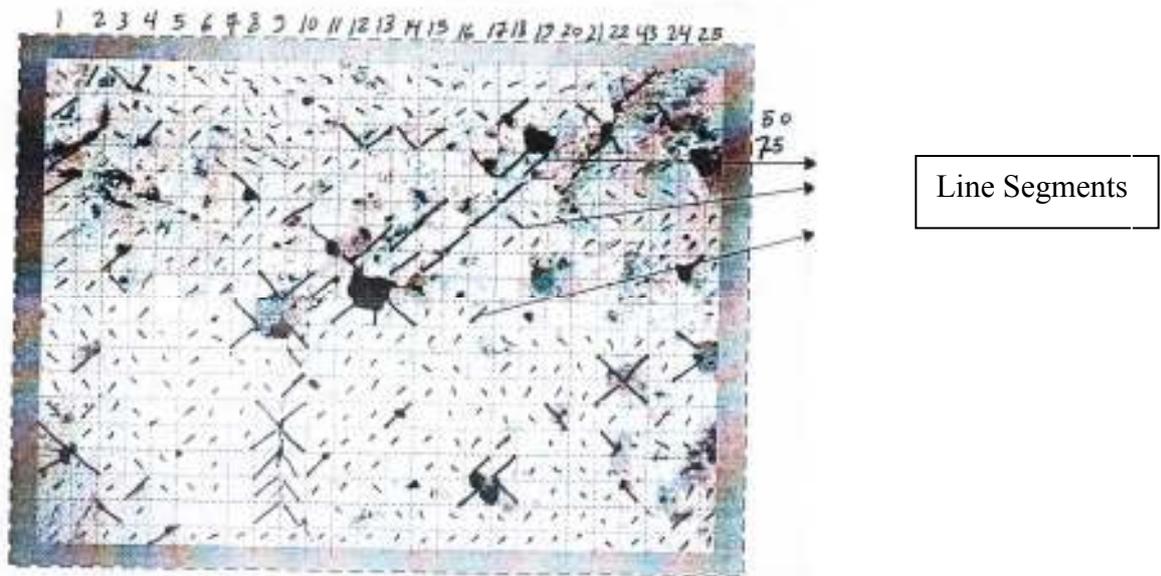


Fig 7: Line segments for the video image indicating the probable crack patterns. (150 pas = 1 mm)

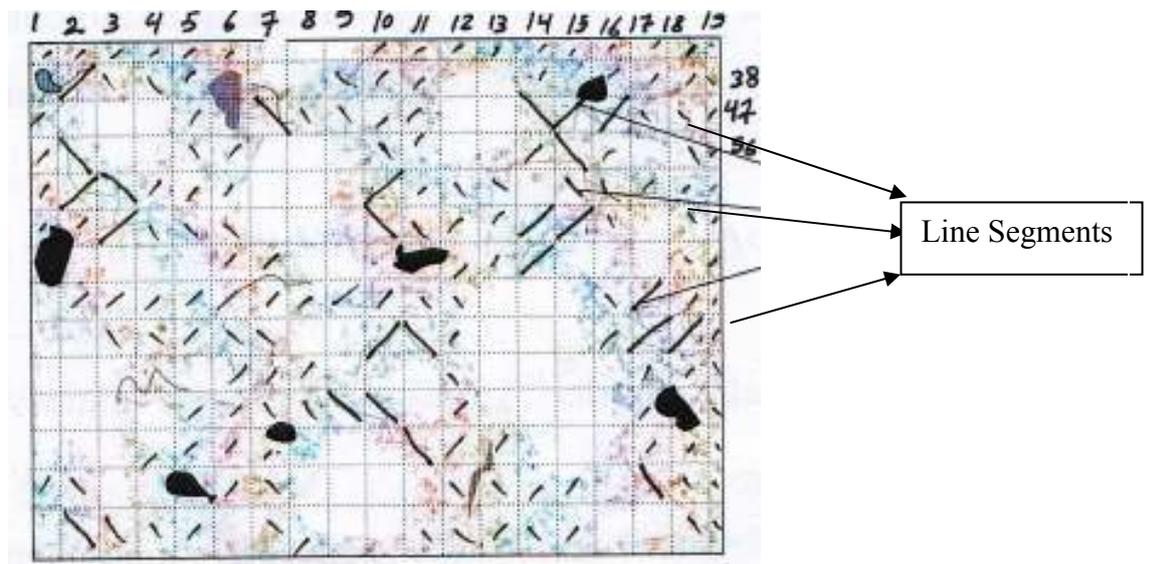


Fig 8: Line segments for the microstructure image indicating the Probable crack patterns.(25 pas = 1 mm)

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