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***Research article***

# Improvement on manufacturing processing time of AAC Block

**Cam M. Nguyen, Tung T. Luu***



**ABSTRACT**

Autoclaved aerated concrete (AAC) was invented in 1920s. AAC is composed of lime, cement, sand, fly ash and aluminum powder, which is the component that plays an important role in creating air voids, an essential factor of the AAC. The production process of the AAC block comprises of stages such as: mixing, casting, cutting, autoclaving, etc. All of the stages are conducted in an eco-friendly manner. The AAC is also called the future of construction materials because of its light weight feature when compared to red bricks along with excellent sound/heat insulation. AAC Blocks will help to reduce the use of cement, sand together with steel and other materials in the construction work. AAC Blocks can be used for both interior and exterior construction. In many construction projects, the AAC block is a more expensive choice than the red brick but the AAC blocks are more often used due to its cheap total construction value. Application of AAC block is very wide such as in industrial constructions, commercial buildings, offices, schools in rural areas, especially in fast construction of houses. The AAC blocks use cement mortar to bond and require a thinner layer than red bricks. Although the bond layer is very thin at only a few millimeters, the strength of the bond is very strong in both cases of load bearing and non-load bearing walls. The AAC Block has many more advantages when compared to other brick types in the construction market, however, the manufacturing process still needs improving to compete with itself in the future. AAC is a kind of cast concrete. The manufacturing process consists of: First, the sand, cement, lime, water, aluminum powder with a reasonable ratio is mixed well until the mixture is slurry. Secondly, the mixture is poured into the mold and left in the mold for a few hours. Thirdly, a transportation device helps to unmold and move the products to the cutting area. At the cutting area, the mixture is cut into blocks and proceeds to the autoclave under heat and pressure for 10 hours. There are many approaches to decrease the manufacturing time of AAC blocks. The main focus of the previous approaches is the forming of air voids when casting. In the traditional method, the aluminum powder will react with calcium hydroxide and water to create hydrogen gas which results in the creation of foam within the concrete. This method takes a long period of time for the reaction to complete. To reduce the time needed, some researchers use air or different reaction methods to create the foam. In this paper, a new approach will be introduced. The reduction of time will be focused on the waiting time before the cutting by measuring the time needed for the material to reach the suitable hardness. Among the 4 stages in producing AAC blocks, the paper will focus on improvement the process of molding and unmolding to reduce the amount of time and also keeping the quality suitable. The paper also presents the method to measure the hardness of the mixture of lime, sand, etc. before cutting.

**Key words:** Autoclaved aerated concrete, Block, AAC

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## INTRODUCTION

Nowadays, the development focus in construction materials is extremely robust to meet the customers' requirements. Requirements for construction material does not only revolve around its cost, but also easy maintenance, heat and sound insulation, durability, environmental friendliness, easy transportation and easy installation. Along side with cement, sand and rock, brick is also a crucial part in construction. Currently, red bricks are commonly used in Vietnam for civil construction. However, the production of red bricks create a large emission of carbon dioxide and harmful gases that spread into the atmosphere, which is the main cause of air pollution and global warming. Besides, manufacturing red bricks requires lots of soil which can be used for agriculture, affecting the national food security. This is a serious problem in global food crisis in the last few years. Vietnamese Government gave a plan to eliminate the use of red bricks in construction, especially projects funded by the government.

There are many kinds of bricks and blocks better for the environment. One of such "green" blocks is the Autoclaved Aerated Concrete (AAC). The block maintains the feature of heat and sound insulation. The AAC block weight is lighter than that of the

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red bricks, which decreases the cost of steel and cement needed for the construction. The bond between blocks is easier to apply and thinner than with red bricks, aiding in the reduction of construction time[1]. The AAC block is also regarded as a "green" type of block because its manufacture also consists of waste materials such as fly ash.

The composition of AAC includes sand or fly ash, cement, Aluminum powder, Gypsum, Sand, Lime[2]. The mixture's proportion of weight can be described as follows:

1 unit of cement, 1 unit of aluminum powder, 0.5 unit of gypsum, 0.2 unit of fly ash and 0.1 unit of lime. The mixture is added with water and stirred using a rotating equipment. Then, the mixture is poured into a mold. The mold is often in a big box shape. This time, the mixture becomes slurry and is kept in the mold for 2 to 5 hours. This stage is called pre-curing, in which, the aluminum powder reacts and produces the hydrogen to create air voids, which makes the mixture expand as a concrete foam. As a result, the density decreases to a value of 500-1400 kg/m$^3$. After this stage, the concrete having the required hardness is sent to the cutting station. Here, steel wires are used to cut the concrete foam into blocks. The blocks are cut in different dimensions, which can be adjusted by the change of distance between the wires. After cutting, the blocks are grouped and then steamed under high pressure.

Figure 1: Concrete foam is cut by steel wires.

After steaming for 12 hours, the strength of the AAC would reach the desired value. The AAC blocks should then proceed to be stored in a proper storage space.

With a highly competitive construction market, the AAC block manufacturers require effective methods to reduce the production cost. One of the cost reduction methods is to decrease the manufacturing time, which leads to an increase in productivity. In Mostafa (2004)[3], the air-cooled slag replaced the sand and lime in AAC. It helped improve the AAC's strength and reduced the manufacturing time. A new approach introduced in Mitsuda et al. (1992)[4] was to measure the curing time to obtain the best strength. The principle of creating foam can be described as follow: the air voids of 0.1 – 1.0 mm is created by the reaction between aluminum and lime. The smaller voids are from the water surrounding the raw material. The research recorded that if the size of the voids were big, the curing time must be increased to obtain the good strength. Thus, the size of the voids must be calculated reasonably to obtain the best time. Another research mentioned the lime's component ratio and an optimal curing time at a certain pressure being experimented. In this research, when the pressure reached 14 atm, the strength of the material would acquire its maximum value with lime's percentage ranging from 10 to 30%. For the optimal lime ratio, the research recommended that lime should make up 20% of the mixture total weight. These parameters help obtain the maximum strength and it only took only 8 hours to complete the curing process. To optimize the manufacturing time, an approach[5] on mathematical models of processing was introduced. Here, the optimization problem was solved to find the minimum time of cutting machines, minimum resources required, optimal cutting patterns, a well-planned manufacturing process; they also performed a careful study to assess the change of demand for the products to optimize manufacturing plans. The result of this study showed that the time for manufacturing AAC blocks from raw materials to clients will decrease.

In this paper, an experimental method to reduce the curing time will be introduced. The experiment will be done to measure the hardness of the concrete at the pre-curing stage. The time of the pre-curing stage is from 4 to 6 hours. The problem is to choose a reasonable time so that the pre-curing time and the cutting time will be minimum but the compressive strength does not change. In addition, a method to measure the hardness of concrete at the pre-curing stage will be presented. The concrete in this stage is still fairly soft to cut by using steel wires as shown in Figure 1. However, if the concrete is too soft, the block will stick together, making it difficult to separate the blocks after autoclaving. In contrast, if the concrete is too hard, it will be too difficult to cut into separate blocks and the steel wires can be broken. The method to decide the reasonable hardness will be introduced in this paper. The rest of the paper will be divided into 3 parts: The method to measure the hardness, Experiments conducted to obtain the reasonable hardness and Conclusions.

## METHODOLOGY

To measure the hardness of soft materials, there are many standards applied in reality. The standard in IEC (2005)[6] is applied for materials with low hardness such as wood or plastic. The method is to drop the test material on a wood surface with a density > 600 kg/m3. The material will then go through a damage assessment. Another standard[7] is used to measure rubber, the method doesn't use the indentation on the surface after a presser applies a force on the surface, this method measures the movement of the indicator when the indicator applies on the surface. If the test material is rubber, the soft rubber will make the indicator move a long distance and the hard rubber will provide opposite results. Because there are many kinds of rubber, many types of indicators can be chosen such as type A, type B, type C, type D for suitable rubber.

Hardness tests mentioned above are for the elastic materials or hard ones. In the AAC case, the concrete is soft and inelastic, thus, if the test in IEC (2005)[6] is applied, the concrete will be flattened and it will be difficult to determine the concrete's hardness. The standard in ASTM International (2015)[7] is too difficult to apply due to the inelasticity of concrete.

To measure the hardness of soft and inelastic materials, a standard in ASTM International (2005)[8] introduced a test using a steel ball with a diameter of 16 mm and a weight of 5 kg. The ball is dropped with an energy of 6.67 J per 1 mm of thickness. Depending on the material, the test can be done with different energy settings 6.7, 5.0, 3.3, and 1.7 J per 1 mm of thickness. A sample of material after testing is shown in Figure 2. The area of denting is measured to determine the compressive strength (Figure 3) which is in relation with the hardness of the material.

In the precuring state, the measuring of the concrete's hardness is particularly important. When the hardness is suitable, the concrete will then be sent to the cutting area. However, it is difficult to choose the "right" time to cut the concrete. To solve this problem, the method of measuring the concrete hardness will use the application of the standard in ASTM International (2005)[8]. The steel ball with a diameter of 50mm will be used. To ensure the energy setting when it is dropped, the steel ball is put in a hollow pipe with a ruler outside (Figure 4). The ruler is used to determine the altitude of the ball, which is a parameter to measure the potential energy. In order to mark the heights on the pipe, we drilled holes on the body with a stepping distance of 10 cm. A latch is put through each hole to keep the ball at the pre-determined positions.

**Figure 2**: Sample after testing with energy of 30.5 J[9].

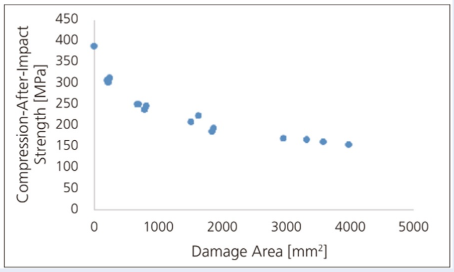


**Figure 3**: Diagram of damage area and compressive strength[9].

The mix of AAC after mixing will be casted, the casting time must satisfy the suitable hardness. The hardness test of concrete at the precuring stage will be measured by using the standard above. The dent after the ball was dropped is shown in the Figure 5. The diameter of the dented surface is measured twice and are taken perpendicular to each other. The diameter of the dent resulted from the test is the average of the two measured values. The diameter will determine the concrete hardness, which then decides the time that the concrete can be sent to the cutting area. The cutting will affect the quality of AAC blocks: if the cutting time is too soon, the blocks will stick to each other and the finishing surface will be scabrous; if the cutting time is too late, the concrete will become too hard and the cutting will take an excessive amount of time and the steel wires are often broken, which requires a halt to the cutting system to replace new wires.

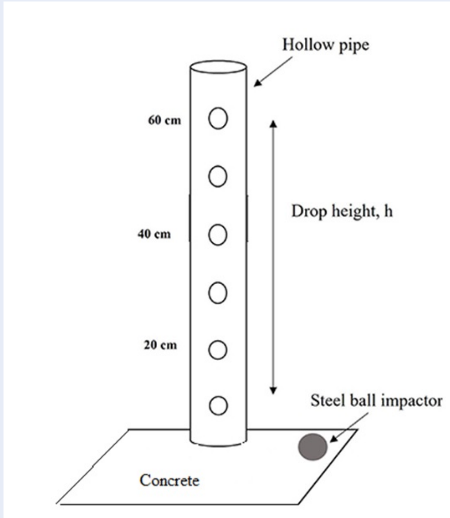


**Figure 4**: Model of hardness test

**Figure 5**: The dent on the concrete surface after test.

## EXPERIMENTAL SETUP

The concrete in the AAC is composed of lime, sand, cement, fly ash, aluminum powder and water, which are mixed and then casted. The casting time was determined by the dropping-ball/ball dropping test. The suggested time for the precuring stage is from 4 to 6 hours. However, the optimal time needed to be experimented on the concrete in the mold at the precuring stage. The process would be divided into intervals of 10 minutes, with a total period of 4 to 6 hours. With each interval, the ball dropping test were conducted 3 times and the diameter in this interval was the average value of 3 test drops. All the values of the diameters were listed and marked on the products.

The concrete after the test was sent to the wire cutting area. In this position, the cutting velocity was kept constant at 6 meters per minute. The diameter of cutting wire was 0.5 millimeters. The moving velocity of the cutting system was 0.2 meter per minute (Figure 6). The cutting time was measured by a digital timer. After cutting, the concrete was sent to the autoclaving stage. Here, the concrete was heated and pressured in 10 hours. Then, the concrete was split into blocks called ACC blocks. However, the work of splitting was not easy; if the hardness of concrete before cutting is low, the splitting will be very difficult and the blocks are often broken and they will become waste products. Thus, the ratio of waste products is an important parameter to evaluate the efficiency of choosing the hardness before cutting.

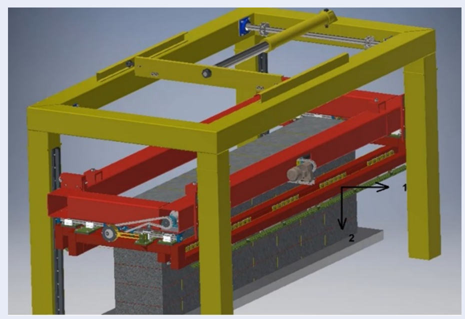


**Figure 6**: Wire cutting machine. 1 is the cutting direction, 2 is the moving direction of the cutting system.

To evaluate the quality of the blocks, they must be measured for the hardness with the different methods from the ball dropping test. Figure 7 shows the machine used to measure the hardness.

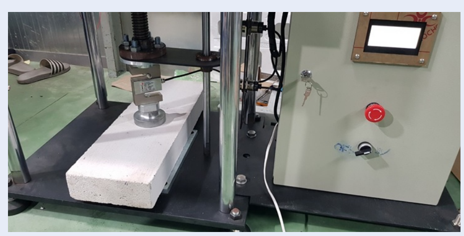

**Figure 7**: The hardness tester.

Thus, to choose the reasonable hardness of concrete before cutting, the parameters that needed to be sampled are: the time required for the concrete to reach the required hardness for cutting, the hardness of the AAC blocks, the time for cutting, the amount of waste products. These parameters needed to be measured and analyzed. However, some parameters will have to be optimized and the others should be kept at a constant value and then vice versa. In these cases, the hardness of AAC blocks will need to satisfy the standard of TCVN 6477:2016, which stated that a standard block M3.5 must endure a compressive stress of 3.5 MPa. The waste product must account for lower than 1% of the total batch. The cutting time must be as low as possible.

The experiment was conducted with the following works: The lime, sand, fly ash, aluminum powder and water were prepared with a ratio researched prior to the test. They were then mixed in a mixer for 1 hour to ensure that all the ingredients were well-mixed. Then, the mixture was poured into the mold. Eighteen molds had been prepared for the experiment. The time for the concrete to reach the required hardness in the casting stage was from 3.5 to 6.5 hours. The tolerance was about 3 hours, thus the first unmold was conducted after 3.5 hours and the time interval for each consecutive unmold was 10 minutes. With each mold, the hardness would be measured before cutting. The molds were numbered from 1 to 18. Each number would be assigned for parameters as follows: hardness before cutting, time spent in the casting stage, cutting time, AAC block's hardness and the ratio of waste products.

## RESULT AND DISCUSSION

The experimental values are presented in Table 1.

From the data in Table 1, the diagrams are drawn in Figure 8. In these diagrams, some comments can be given as follows: The hardness of concrete at the casting stage will increase when the time of casting increases. However, when the casting time is more than 5 hours and 30 minutes, the hardness may not increase. Thus, to achieve optimal results for the AAC, the amount of time should be shorter than 5 hours and 30 minutes. From Figure 8b, we can see that the cutting time will increase if the casting time is also increased. That means the casting time should be chosen at the soonest moment possible. In Figure 8c, the ratio of waste is lowest when the casting time is from 3 hours and 50 minutes to 4 hours and 20 minutes. If the casting time is less than 3 hours and 40 minutes, the cutting is very easy but the blocks will stick together after cutting. As a result, after the autoclaved aerated stage, the blocks become very difficult to be split, which leads to waste products. In addition, if the casting time is longer than 4 hours and 20 minutes, the waste products are also reduced. This is due to the fact that as the concrete at the cutting stage is harder and harder, the splitting becomes very easy; this creates a reduction in the amount of waste products. However, when the concrete is too hard, the cutting stage will become difficult and the cutting wires are often broken and need replacing, thus the time at this stage will increase fast. In addition, the cost of cutting wires and labor is also a big problem that requires some attention. Figure 8d shows the hardness of AAC block after finishing. The hardness will be unchanged when the casting time reaches 5 hours and 10 minutes.

From the experimental data and the comments, the discussions are:

- If the priority is to optimize waste products, the casting time should be more than 4 hours.
- If both reducing the waste products and optimal manufacturing time is equally important, the casting time should range from 4 hours to 4 hours and 30 minutes.
- If the quality of the AAC blocks and the time of production are the priorities, the casting time should be between 4 hours and 20 minutes to 4 hours and 30 minutes.

For the production of the AAC Block, manufacturers want to obtain the optimal production time, maximum benefit and high quality. With these requirements and from the results of experimental data, the casting time should be 4 hours and 20 minutes. In reality, if the manufacture line is different, the time may vary. In this case, the exact time can be obtained by measuring the hardness of concrete at the casting state. This hardness is measured by steel ball drop test and the diameter should be around 19 millimeters.

## CONCLUSION

The AAC block is a type of eco-friendly construction material. With light weight and good insulation, they will be prioritized in construction. However, the competition in manufacturing AAC block leads to the improvement of manufacturing process. To measure the hardness of concrete being soft, the steel ball test was applied and results have been very bright when it was proved that the production time was reduced. From the experimental data, this paper's results showed that the best period of time for the casting stage was approximately 4 hours and 20 minutes and the hardness measured by the steel ball drop test was around 19 millimeters.

**Table 1**: **Experimental data**

| Number | Hardness before cutting (mm) | Time at the casting stage (After 3,5 hours) (Minute) | Cutting time (Minute) | AAC block hardness (MPa) | Ratio of waste products (%) |
|---|---|---|---|---|---|
| 01 | 45 | 10 | 5 | 4 | 10 |
| 02 | 45 | 20 | 5 | 4,1 | 6,5 |
| 03 | 43 | 30 | 6 | 4,3 | 5 |
| 04 | 41 | 40 | 7,2 | 4,4 | 3,7 |
| 05 | 38 | 50 | 8 | 4,5 | 3 |
| 06 | 35 | 60 | 8,7 | 4,55 | 3 |
| 07 | 30 | 70 | 10 | 4,6 | 3 |
| 08 | 25 | 80 | 11 | 4,65 | 3 |
| 09 | 22 | 90 | 13 | 4,7 | 3 |
| 10 | 19 | 100 | 14,5 | 4,8 | 3 |
| 11 | 15 | 110 | 16 | 4,9 | 2,9 |
| 12 | 11 | 120 | 17 | 5 | 2,9 |
| 13 | 8 | 130 | 19 | 5 | 2,9 |
| 14 | 6 | 140 | 21 | 5 | 2,9 |
| 15 | 6 | 150 | 23 | 5 | 2,9 |
| 16 | 6 | 160 | 25 | 5 | 2,9 |
| 17 | 6 | 170 | 26 | 5 | 2,9 |
| 18 | 6 | 180 | 26 | 5 | 2,9 |

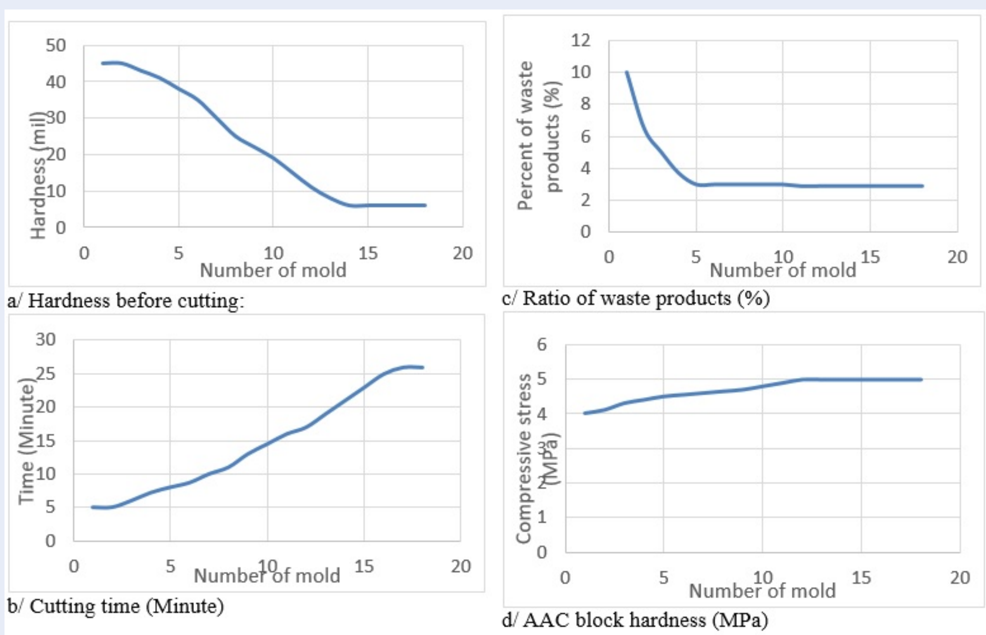


**Figure 8**: Diagram of experimental data

## ABBREVIATION

HCMUT: Ho Chi Minh City University of Technology.

## CONFLICT OF INTEREST

Authors have ensured that there is no conflict of interest in this paper.

## AUTHORS CONTRIBUTION

Authors: Cam M. Nguyen and Tung T. Luu conducted the works in this paper.

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*Bài nghiên cứu*

# Tối ưu thời gian chế tạo gạch Block AAC

**Nguyễn Minh Cảm, Lưu Thanh Tùng***



**TÓM TẮT**

Bê tông khí chưng áp (AAC) được phát minh vào những năm 1920. AAC bao gồm vôi, xi măng, cát, tro bay và bột nhôm đóng vai trò quan trọng để tạo ra lỗ rỗng không khí, một yếu tố thiết yếu của AAC. Để sản xuất được khối AAC sẽ trải qua các công đoạn như: trộn, đúc, cắt, hấp tiệt trùng ... Tất cả các công đoạn đều xanh do thân thiện với môi trường. Nó còn được mệnh danh là vật liệu xây dựng của tương lai vì trọng lượng nhẹ khi so sánh với gạch đỏ, cách âm, cách nhiệt tốt. AAC Block sẽ giúp giảm thiểu việc sử dụng xi măng, cát cùng với thép và các vật liệu khác trong xây dựng. Gạch AAC có thể được sử dụng cho cả nội thất và ngoại thất. Trong thực tế xây dựng, gạch AAC đắt hơn một chút so với gạch đỏ nhưng gạch AAC được sử dụng nhiều hơn do giá trị xây dựng rẻ. Ứng dụng của gạch AAC rất rộng rãi như xây dựng công nghiệp, thương mại, văn phòng, trường học ở nông thôn, đặc biệt là xây dựng nhà cấp tốc. Khối AAC sử dụng vữa xi măng để liên kết với nhau và chỉ sử dụng một lớp mỏng hơn so với gạch đỏ. Mặc dù lớp liên kết rất mỏng, vài mm nhưng liên kết cường độ rất bền trong cả trường hợp tường chịu tải và không chịu tải. Gạch AAC có rất nhiều lợi thế so với các loại gạch khác trên thị trường xây dựng, tuy nhiên, quy trình sản xuất vẫn cần cải tiến để có thể cạnh tranh với chính nó trong tương lai.

AAC là một loại bê tông đúc. Quy trình sản xuất bao gồm: Đầu tiên cát, xi măng, vôi sống, nước, bột nhôm với tỷ lệ hợp lý sẽ được trộn đều để tạo thành dạng sệt, sau đó, hỗn hợp này được đổ vào khuôn trong vài giờ. Sau đó, một cần trục giàn sẽ giúp dỡ hàng và di chuyển sản phẩm đến khu vực cắt. Tại đây, chúng sẽ được cắt thành từng khối và mang đi hấp dưới nhiệt độ cao và áp suất trong 10 giờ. Có rất nhiều cách tiếp cận để giảm thời gian xử lý sản xuất của khối AAC. Họ tập trung vào việc tạo ra khoảng trống không khí khi đúc. Theo phương pháp truyền thống, bột nhôm sẽ phản ứng với canxi hydroxit và nước để tạo ra khí hydro tạo ra bọt trong bê tông. Phương pháp này cần nhiều thời gian để chờ phản ứng. Để giảm thời gian, một số nhà nghiên cứu sử dụng không khí hoặc các phương pháp phản ứng khác nhau để tạo bọt.

Trong bài báo này, một cách tiếp cận mới được giới thiệu. Việc giảm thời gian sẽ được tập trung vào quá trình xử lý. AAC block sẽ trải qua 4 giai đoạn, bài báo sẽ cho quá trình xử lý khuôn tối ưu trong việc tháo và dỡ khuôn để giảm thời gian và giữ cho chất lượng ổn định. Bài báo cũng trình bày phương pháp đo độ cứng của hỗn hợp vôi, cát ... trước khi cắt.

**Từ khoá:** Bê tông khí chưng áp, Gạch khối, AAC

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