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Mechanical Behavior of Concrete, Made with Micro-Nano Air Bubbles

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ABSTRACT: Nano materials have been widely used in laboratory and industrial scales in order to improve various properties of concrete and concrete mixture. The mainstream practice of the researches in this field is to add metallic nano-particles into the concrete mixture. The present research focuses on adding Micro-Nano Air Bubbles (MNAB) into water before mixing it with aggregate and cement mixtures. It studies the compressive and tensile strength as well as other engineering properties of the concrete such as the initial and final setting time and the variation in temperature during the setting. The ratio of water/cement was 0.6 with three specimens, prepared for each mixed design to ensure the data quality. Results showed that MNAB-made concrete had 19% higher compression and 16% tensile strength, while the initial and final setting times were significantly shorter (approximately a half) and hydration temperature was notably lower than ordinary concrete.

Keywords: Compression Strength, Concrete, Micro-Nano Air Bubble, Setting Time, Tensile Strength, Workability.

INTRODUCTION

Properties, behavior, and performance of concrete are greatly affected by the aggregate minerals and texture, not to mention the type of cement, used in the concrete paste. In recent decades, additives made their way into the concrete mixture to improve various properties of the final product or the mixture paste. More recently, nano additives such as nano tubes, nano metallic oxides, and nano fabrics were widely used for scientific researches as well as industrial purposes (Pradesh, 2012).

Nano particles of SiO_2 (Boshehrian and Hosseini, 2011), TiO_2 (Salemi et al., 2014; Nazari et al., 2010a), Al_2O_3 (Nazari et al., 2009 and Nazari et al., 2010b), and Fe_2O_3 (Abdoli Yazdi et al., 2011; Nazari et al., 2010c) improve the compression strength of the concrete while ZnO (Behfarnia et al., 2013) and ordinary bubbles, made by plasticizers (Kosmatka et al., 2003) affect the concrete strength reversely. TiO_2 is used as concrete coating to remove NO_X (Guoet al., 2013). There is a limit, beyond which Nano materials can affect the compressive strength of the concrete reversely as a result of the decrease, seen in the crystalline $Ca(OH)_2$, which is essential for C-S-H gel formation, while higher rates of Nano particles may reversely affect the

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homogeneity of the mixture (Nazari and Riahi, 2011). A review of the application of nano particles on the properties of concrete was provided by Rathi and Modhera (2014).

Micro-Nano Air Bubbles (MNAB) is one of the Nano-sized materials, formed in aqueous media, which has been studied from various points of view in recent years. A comprehensive text on formation and applications of MNAB could be found in Tsuge (2015). It is known that MNAB increases pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), turbidity, and nitrogen content in water (Mozaffari Naeeni, 2014). Li et al. (2014) reported that generating MNAB with and without surfactant may affect the size distribution toward finer bubbles. It could be concluded from their results that the maximum concentration of DO is controlled by the total MNB in the media in a way that the concentration of Micro-Nano Oxygen Bubbles (MNOB) and Micro-Nano Air Bubbles (MNAB) are almost equal. If the bubbles' sizes in both cases are the same, one can conclude that the numbers of bubbles are equal as well.

Application of MNAB to a concrete mixture is not reported in the literature up to this date. The present research was conducted to study the changes in the behavior and characteristics of the concrete and concrete paste if MNAB is applied to the water in concrete mixture.

MATERIALS AND METHODS

To study the effect of MNAB on mortar and concrete, a series of experiment was designed and performed in laboratory scale. Compression, tensile, and flexural strengths of ordinary concrete were compared to their MNAB-made equivalents, using same material of identical ratio in the final mixture. It should be noted that addition of MNAB does not change the water density and, consequently, the water to cement ratio. The setting time and slump of the mortar for both cases were measured and compared. To evaluate the temperature during the setting, a specific test configuration was designed and manufactured, the detail information of which are presented in the following subsections.

The Aggregate

The river source aggregate was used in this research. The aggregate was consisted of fine sand (< 2 mm), coarse sand (10 mm), and gravel (< 25 mm). The aggregate did not receive any further treatment; therefore, the results would be applicable to real engineering works. Since the study aimed to have a comparative evaluation of applying MNAB to concrete mixture, the same aggregate was used for all samples in each experiment.

Water

Tap water was taken from Shahrood City water supply system. The MNAB was produced hydro-dynamically by an invented device (Iranian Patent #83998) that increased the pH up to 9 and led to a smooth uniform bubble size distribution as shown in Figure 1.

As another characteristic of the water with MNAB, the Zeta potential was also measured in a range from-30 to -10 as well as 0 to 10 mV with an average of -20.28 mV.

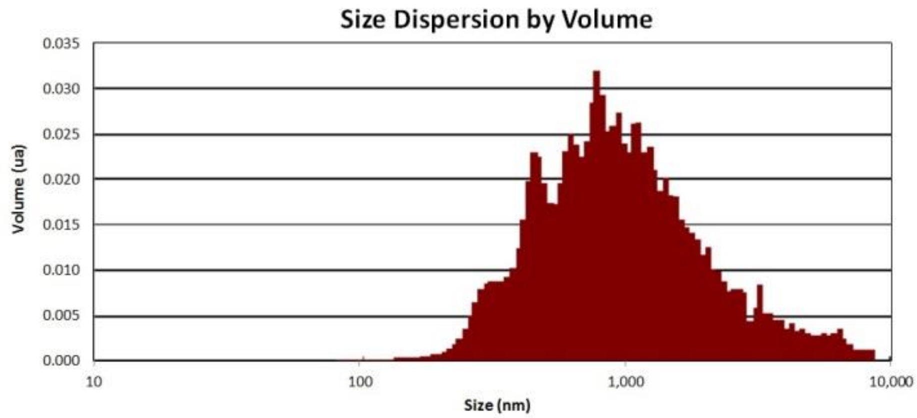
Cement

The Type II cement was purchased from Shahrood Cement Co. This is the most common type of cement, used for concrete mixture and masonry. Table 1 provides the details of cement's chemical analysis.

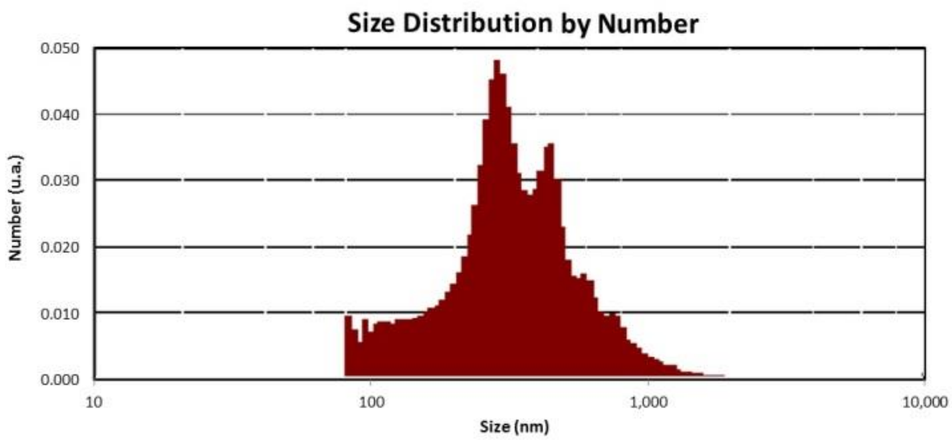
The Concrete Mixture

The concrete mixture was designed according to the preliminary test in the laboratory. Table 2 gives the portions of its production. The aggregate consisted of fine sand, coarse sand, and gravel with a weight ratio of 1:1:2.

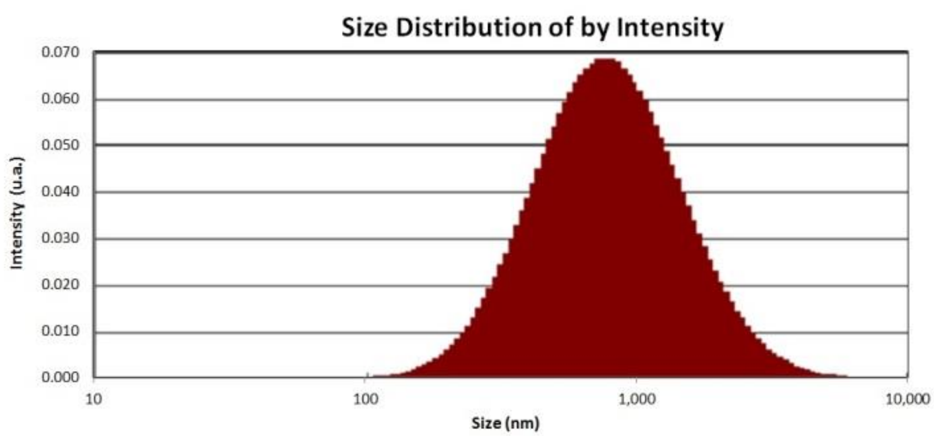
Iranian Standard 581 was used for concrete production and curing.



a) Size dispersion of MNAB by volume



b) Size distribution of MNAB by number



c) Size distribution of MNAB by Intensity

Fig. 1. The size distributions of MNAB in water

Table 1. Chemical properties of cement

Chemical Profile	Average (%)	ISIRI 389 (%)
SiO_2	21.11	At least 20
Al_2O_3	4.41	Maximum 6
Fe_2O_3	3.95	Maximum 6
CaO	63.55	---
MgO	1.52	Maximum 5
SO_3	2.74	Maximum 3
K_2O	0.55	-
Na_2O_3	0.41	-

Table 2. Weight ratio of materials used in the manufacture of concrete examples

Materials	Unit	Weight
Weight of Cement	Kg	350
Weight of Water	Kg	210
The Total Weight of Aggregate	Kg	1840

Tests on Cement and Concrete

The setting tests were conducted based on ISIRI 392 by Vicat needle. The cement paste was prepared with 500 g cement and 130 mL water (giving a water to cement ratio of 0.26).

Since the available standard tests focus on the thermal energy, released during the hydration, an innovative experiment was designed to investigate the effect of MNAB on the hydration temperature. After some trials, a 1:1 ratio of water and cement was selected for the test. As a result, 100 gr cement and 100 mL water were mixed and put in a reactor, placed in a thoroughly-insulated flask. The concrete temperature during the hydration was measured with TPS Smart CHEM-Lab temperature probe. The temperature data was collected every 15 second and stored as a sequence of temperature time in the computer. To remove as many causes of error as possible, all materials were kept in room temperature for 24 hours prior to the test.

The compressive strength tests were performed on the samples in 7 and 28 days after the production and the hydraulic jack was set for the loading rate of 7 kN/s.

The tensile strength was performed according to ISIRI 6047 or the so-called Brazilian tensile test.

RESULTS AND DISCUSSIONS

Initial and Final Setting Times

Since the observations along with the preliminary test showed that workability of MNAB concrete is lower than ordinary concrete, the Vicat needle test was performed to assess the change in setting time. The triplicated test showed that the setting time is quite shorter in MNAB cement paste, compared to the cement paste, made with tap water. The results are presented in Figure 2. As seen in this figure, the MNAB causes the early or almost immediate initiation of hydration while in the ordinary cement paste, the setting starts following at least a period of 45 minutes after the beginning of the test. Results showed that MNAB's effect is similar to Nano-cement which reduces the setting time. The initial setting for mortar after replacing 50% of cement with its Nano variety drops from 70 min to 30 min, which is still longer than the case with the concrete, made with Type II cement and MNAB, where the setting time is lowered from 60 min to less than 15 min (Figure 2).

The final setting time (zero penetration of the needle) was recorded at 135 and 255 min for MNAB and ordinary cement pastes respectively.

Hydration Temperature

Hydration is an exothermal reaction, responsible for thermal cracks in massive concrete elements. There are some methods to predict the maximum temperature in the curing concrete (Riding et al., 2006) but the temperature variation has not been thoroughly investigated. For practical use, some precautions are recommended in the codes and literature so that the cracks could be avoided during the cement setting. In the present study, both pastes, namely cement with water and water-added MNAB, were investigated and the time sequence of the temperature in a mixture of 100 gr cement and 100mL water was recorded, as shown in Figure3. Since the majority of researchers focus on compression strength as the main parameter in Nano-material-made concrete, less attention has been given to other concrete and mortar properties such as temperature during the setting and the authors were not able to find a published material, concerning this issue.

An interesting point, evident from the figure, is that even though the patterns are identical, the MNAB reduces the temperature of the concrete paste during the setting.

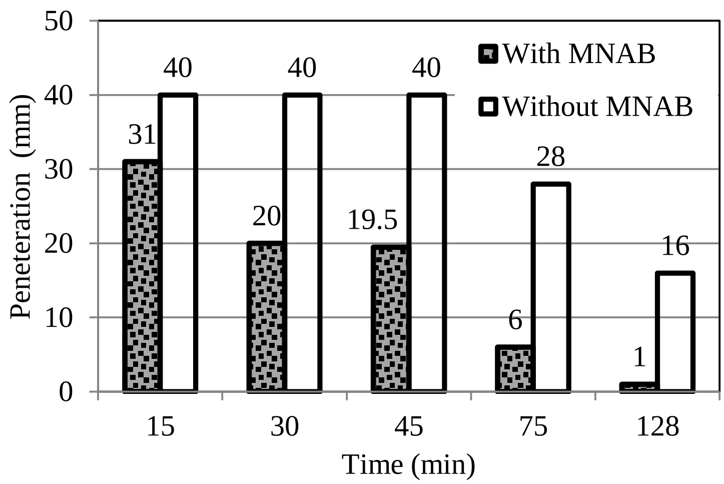


Fig. 2. The results of Vicat needle test on the cement paste, with and without MNAB

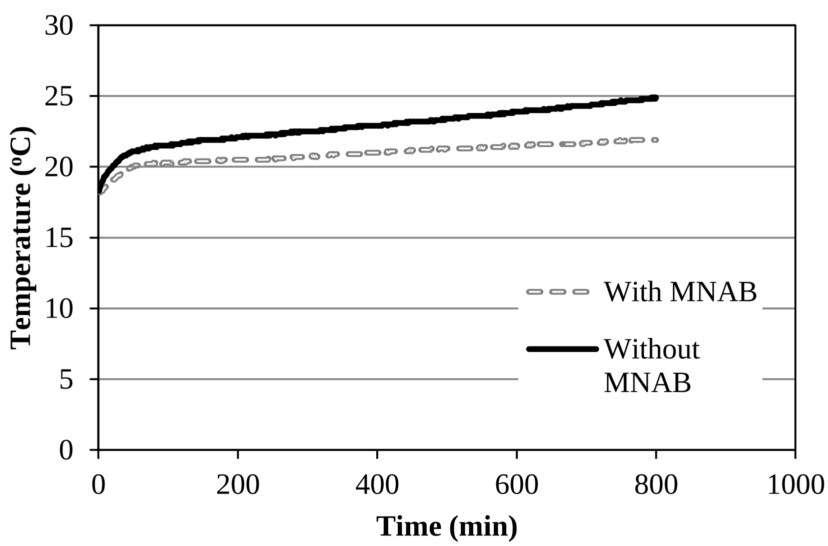


Fig. 3. The temperature variation during the setting of cement paste, with and without MNAB

Slump Tests

Slump tests were performed on 3 sets of samples, as shown in Figure 4. Here it can be seen that addition of MNAB to water for concrete production drastically lowers the workability of concrete, in contrast to the micro bubbles, created with the plasticizers. Slump reduction in these tests ranged from 6 to 10 mm with an average of 8 mm, equal to 13.55 percent of the concrete slump. This reduction was previously reported for other Nano-additives such as nano-TiO_2, nano-Al_2O_3, nano-Fe_2O_3, and nano-ZnO_2 at 41, 37.5, 50, and 25 percent respectively (Salemi et al., 2014). It was reported that addition of 0.5 to 1 percent of air bubbles to concrete increases the slump up to 25 mm (Kosmatka et al., 2003). These results agree with the fact that the setting time for MNAB mortar is much less than ordinary mortar. However, Rathi and Modhera (2014) noted that Nano SiO_2, TiO_2, Al_2O_3, and ZrO_2 particles require use of super-plasticizers to improve the workability of concrete at lower ratio of water to cement.

Compression Strength Tests

In order to compare the compression strength of ordinary concrete with MNAB, the cubic samples underwent the test after 7 and 28 days. Figures 5a and 5b show the results.

As evident in the figure, the compression strength was clearly improved with the use of MNAB in water. By averaging the results, an increase of 19% in f_c is calculated. It should be mentioned that the reason for this change is unknown since it is outside the scope of this research but the change in physic-chemistry of water properties could be responsible for the change. According to Rathi and Modhera (2014) addition of nano material into the order of 1 to 4% of cement weight improves the concrete compression strength. Naji Givi et al. (2010) reported that addition of 1% nano SiO_2 of 15 nm could improve the compression strength up to 18% while 1.5% of the same nano particle on 80 nm size elevated 11% of the compression strength, both less than the strength, increased by adding MNAB. Furthermore, MNAB concrete is easier to use and less expensive. Saloma et al. (2013) reported an increase of 25% in compression strength by adding nano-silica (10-140 nm) to the concrete up to 10% of the weight of cement.

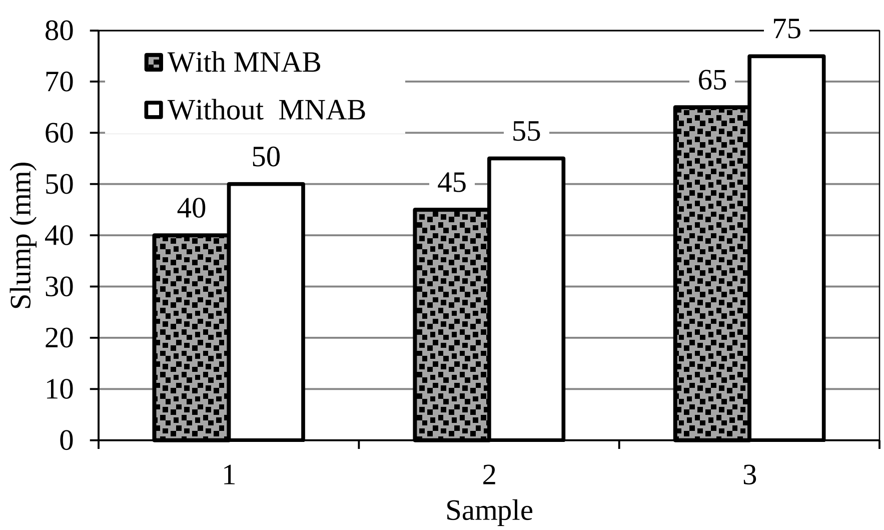
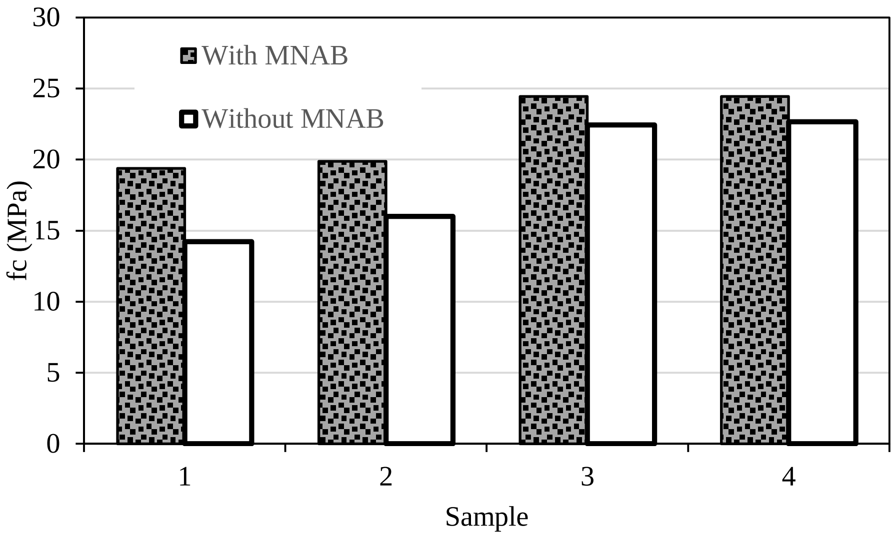
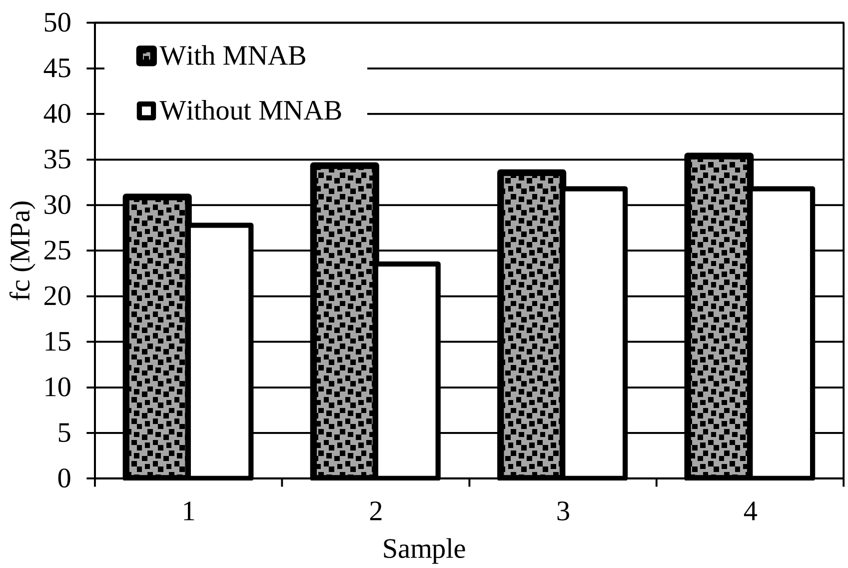


Fig. 4. The results of slump tests



(a)



(b)

Fig. 5. The compression strength of the concrete samples in a) 7 days and b) 28 days

Tensile Strength

The tensile strength was determined by testing two sets of concrete samples, each including three ordinary and three MNAB-containing concrete. Figure 6 demonstrates the results.

Overall, a 16% increase in tensile strength was observed. Results show considerably-lower tensile strength increase by MNAB than what Naji Givi et al. (2010) reported, being 80% more than the ordinary concrete. Such increment is much higher than the compression strength improvement by the same material.

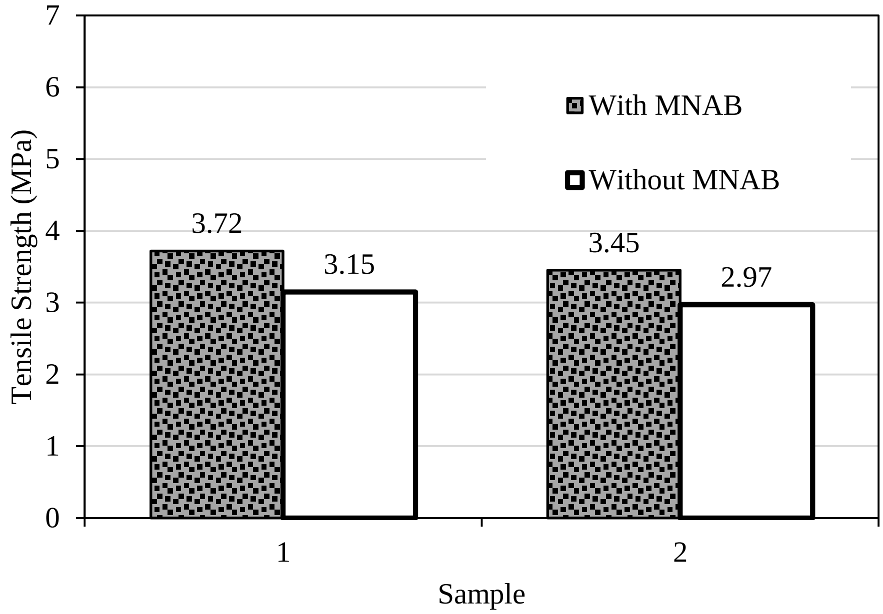


Fig. 6. The tensile strength of concrete

CONCLUSIONS

This paper investigated the application of Micro-Nano Air Bubbles (MNAB) to the water, used for concrete production. Results show that MNAB could effectively improve the mechanical properties of the concrete while reducing its workability. It was observed that compression and tensile strength increased for 16 and 19% respectively, while the temperature during the setting dropped remarkably. The initial and final setting times were also reduced, meaning that this kind of concrete needs to be cast in shorter periods of time, compared to the ordinary concrete.

These findings could attract the attention of those industries which are working on precast concrete where the less setting time is usually followed by a lower production cost. The manufactures of concrete massive blocks, which usually generate a big amount of heat during the setting and consequently fine cracks, also may benefit from MNAB technology.

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