

Analysis of Size Effect of Concrete Aggregate by Nuclear Magnetic Resonance

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Abstract—In order to study whether different concrete aggregate sizes have certain effects on the mechanical properties of concrete, three specimens with different concrete aggregate sizes were scanned by low field nuclear magnetic resonance testing method after fatigue test loading in this paper. By testing the transverse relaxation time of the three specimens, i.e. T2 spectrum, and NMR imaging, it is found that the test data of the three specimens are different and show some regular changes. Through further testing and analysis, it is concluded that different concrete aggregate size has certain influence on the mechanical properties of concrete. This result provides important help for scholars to study the size effect of concrete aggregate.

Keywords—concrete; aggregate; size effect; Nuclear Magnetic Resonance(NMR); T2 Spectrum; NMR imaging

I. INTRODUCTION

Concrete is a heterogeneous and anisotropic engineering composite material composed of fine aggregate such as cement, sand and coarse aggregate such as stone. This material is widely used in industrial and civil buildings. But in some accidents, some concrete members fail to reach the design strength and then fail [1-2]. Scholars from all over the world have shown that the mechanical properties of concrete materials are also affected by size effect [3-5]. This paper mainly studies the size effect of concrete specimens due to the different size of coarse aggregate.

Nuclear magnetic resonance as an advanced material diagnostic technology [6-8], it has been widely used in life science, oil drilling, macromolecule materials, porous materials, textile industry and other industries at present. Low-field NMR [9-10] mainly refers to the small field intensity of the applied alternating magnetic field, generally below 1 Tesla. The low-field NMR instrument used in this paper is about 0.2 Tesla of the applied magnetic field intensity. In this paper, the effect of size effect on the failure and damage of concrete specimens under fatigue loading to a certain extent is studied by using the T2 spectrum and NMR imaging of the instrument. The aggregate sizes of concrete specimens in this paper are 5-10mm, 5-15mm and 5-20mm, respectively, expressed by A, B and C.

II. LOW-FIELD NMR ACQUISITION

If there is a pore in the damaged specimen, water will enter the pore after being saturated. Nuclear magnetic resonance (NMR) is to detect H protons in the sample, and thus pore. The specific process is that as the sample is placed in the magnetic field, the collector emits radio frequency pulses and maintains a

certain frequency basis. The H proton in the sample will appear resonance phenomenon and absorb the pulse energy generated before. At the end of the pulse, H protons release the received energy. At this time, the special coil in the instrument can completely detect this process, which is what we call nuclear magnetic resonance signal. For the sample, the interior is not completely consistent, so the release time of energy is long or short. Through this difference, we can get some rules from it and study the internal properties of samples accordingly.

A. Test Instrument

In this experiment, NMR data were collected by Shanghai Niumag Electronics Technology Company. The instrument model is MacroMR12-150H-I large-aperture nuclear magnetic resonance analysis and imaging system. As shown in Figure 1.



FIGURE I. LOW FIEALD MRI INSTRUMENT

B. Test Specimen

Three specimens, A, B and C, were loaded 500,000 times under fatigue test, and then tested by magnetic resonance scanning. In this paper, the stress level of fatigue loading is 0.75. The NMR test specimens are shown in Figure 2.

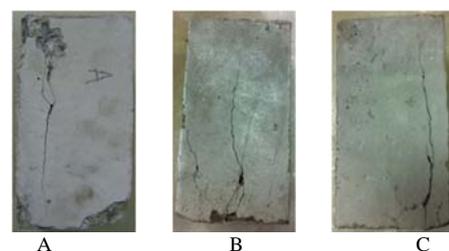


FIGURE II. SPECIMENS TO BE TESTED

C. Test Process

- After fatigue loading, the specimen to be tested is saturated for 24 hours in a vacuum pressurized saturation device.
- Setting up test parameters. In T2 experiment, CPMG sequence was used. The sequence parameters are: PRG = 1, NS = 16. MR imaging test, using SE sequence, cross-sectional imaging, imaging thickness is the same as the sample. The sequence parameter is: P1=1200us; D0=1500ms; D1=0.1ms; D2=1ms; D4=0.1ms; D5=0.1ms; D9= 0.1ms; D10=3ms; GA3=80; GA4=20; GA5=12; RP1Count=16; RP2Count=192.
- Acquisition and analysis with MacroMR12-150H-I low-field nuclear magnetic resonance acquisition instrument.

D. Test Principle

The principle of this NMR instrument can be summarized as follows: The whole instrument is under the control of a computer. It generates radio frequency signals and the DDS device which can satisfy the resonance condition starts to work. By controlling the waveform modulation signal, the signal is transformed into the required shape for resonance. Then the signal is transmitted through the RF power amplifier system, and the final result is the NMR of the sample. In the process of signal acquisition, the RF coil can accept this part of the signal, amplify it after a series of activities, and finally enter the analog-to-digital converter. Then collect the data needed to make this part of the data into the computer. Through the processing of relevant programs, the NMR spectrum can be obtained in the computer. If it is a two-dimensional nuclear magnetic resonance imaging sequence, three signals need to be emitted in the pulse sequence generator. After gradient power amplification, three-dimensional gradient magnetic field is formed on the gradient coil. This method can locate the signal in space, and after processing by computer, the final two-dimensional image can be obtained.

III. COMPARISON OF DATA COLLECTED FROM DIFFERENT SAMPLES

In this paper, T2 spectrum acquisition and NMR imaging of fatigue loaded A, B and C specimens are carried out.

A. Comparison of T2 Spectra

T2 spectrum, also known as transverse relaxation time, is a time constant describing the recovery process of transverse component of nuclear magnetization. The diagram of lateral relaxation is shown in Figure 3. Relaxation is to add a radio frequency pulse to the specimen, which makes the hydrogen nucleus in the specimen become magnetic resonance after being saturated. After reaching a stable high energy state, the external magnetic field is removed and the process of restoring the magnetic moment state before the magnetic resonance occurs begins. The relaxation process is actually the process of restoring the magnetic moment to the past. The time used in this process is the relaxation time. When the tested specimens

are fully saturated with water, the echo intervals are relatively small, and the T2 spectrum corresponds well with the pore size distribution of concrete specimens. The more voids the specimen has, the more water it contains when it is fully saturated, the stronger the signal during the NMR test. On the contrary, it is the same, that is, the larger the NMR signal quantity, the more hydrogen atom content in the specimen, indicating that there are more voids. The magnitude of the longitudinal coordinate of T2 spectrum represents the signal quantity of NMR. The larger the peak values of the magnitude in T2 spectrum, the larger the large aperture in the specimen, so that we can judge the internal failure of the specimen.

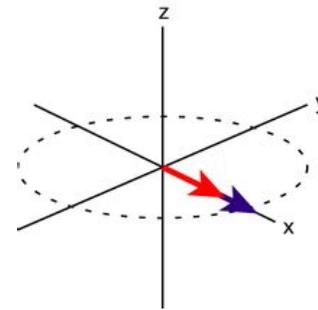


FIGURE III. SCHEMATIC OF TRANSVERSE RELAXATION

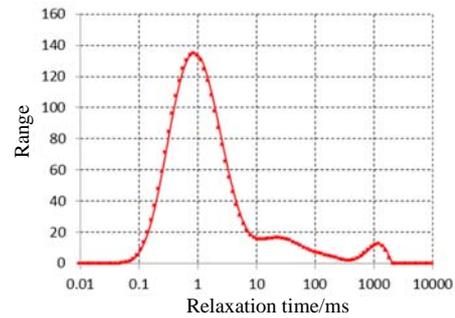


FIGURE IV. T2 SPECTRUM OF A SPECIMEN

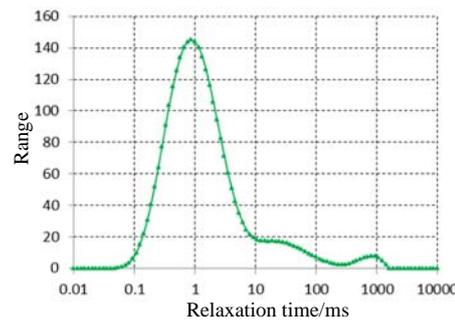


FIGURE V. T2 SPECTRUM OF B SPECIMEN

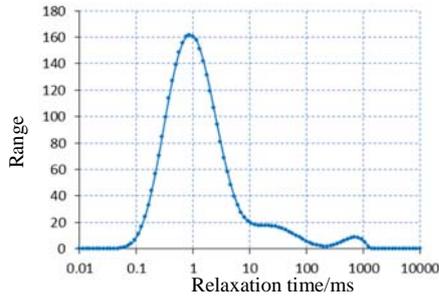


FIGURE VI. T2 SPECTRUM OF C SPECIMEN

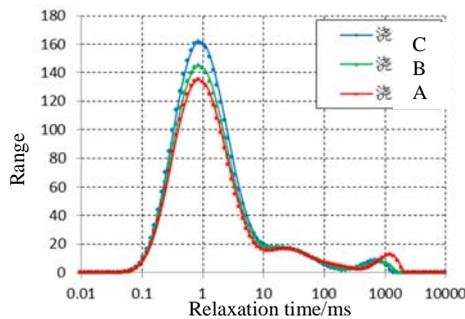


FIGURE VII. COMPARISON OF T2 SPECTRA OF THREE SPECIMENS

The relationship between the amplitude and relaxation time of NMR signal can be obtained by sorting out the test data after testing, as shown in Figure 4-6. Figures 4-6 are T2 spectra of concrete specimens with aggregate size of 5-10 mm, 5-15 mm and 5-20 mm, respectively.

Figure 7 is a comparison of T2 spectra of three samples. It can be found from Figure 7 that the maximum peak value of T2 spectrum of C sample with the largest aggregate size is the largest, that of A sample with the smallest aggregate size is the smallest, and that of B sample is between the two.

B. Nuclear Magnetic Resonance Imaging of Different Samples

Figure 8 is a diagram of the coil imaging direction for magnetic resonance imaging. When imaging, it is necessary to put the sample into the coil. The image obtained by imaging the plane perpendicular to X-axis is sagittal, cross-sectional and coronal images are obtained from the plane perpendicular to Y-axis and Z-axis.

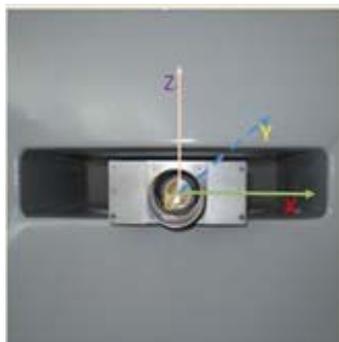
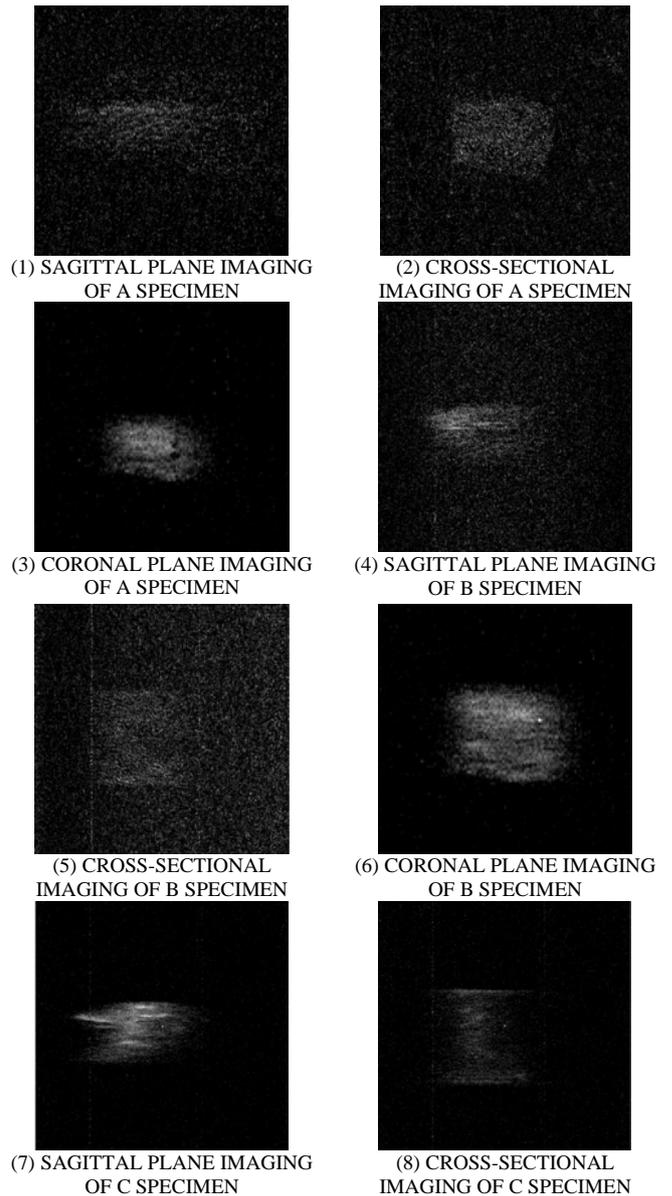
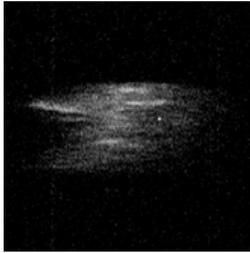


FIGURE VIII. SCHEMATIC DIAGRAM OF COIL IMAGING DIRECTION

Different concrete specimens were imaged by magnetic resonance imaging (MRI). The imaging results of the specimens are shown in Figure 9. The bright area in the image is the sample image, and the surrounding black area is the background color. The brighter the color in the image, the higher the water content in the area and the bigger the T2, that is, the larger the pore size. It can be seen from the imaging images of the three surfaces of the sample that the brightness region of the image is not uniform, which indicates that the pore distribution in the sample is complex.





(9) CORONAL PLANE IMAGING OF C SPECIMEN

FIGURE IX. NUCLEAR MAGNETIC RESONANCE IMAGING

As can be seen from Figure 9, the brightest color is found in the C sample with a diameter of 5-20 mm and the darkest in the A sample with a diameter of 5-10 mm. The brighter the color is, the more water is contained in the specimen, that is, the more pore is. The image further shows that the pore size of the large aggregate size specimen is smaller than that of the aggregate, and the pore size of the cutting specimen is larger than that of the casting specimen. It also shows that the large aggregate size specimen with smaller aggregate size is more prone to local catastrophic damage.

IV. CONCLUSION

We have carried out many tests on a large number of specimens and obtained the same regularity of data. From the analysis of T2 spectrum and NMR image in Nuclear Magnetic Resonance, it can be concluded that the size effect of different aggregate sizes has certain influence on the localized catastrophic damage of concrete specimens after fatigue compression. We conclude that the larger the particle size of aggregate, the more the internal voids, the larger the pore size, the deeper the localization degree, and the more likely catastrophic damage will occur. The damage amount of specimens with larger aggregate size is also larger, and the damage amount of specimens with smaller aggregate size is relatively smaller. And with the increase of aggregate size, the damage increases faster.

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