SMiRT–12 / K. Kussmaul (Editor)

H07/5

EFFECT OF DRYING AND WATER SUPPLYING AFTER DRYING ON TENSILE STRENGTH OF CEMENT MORTAR

K. Takiguchi and H. Hotta

ABSTRACT

The influence of drying and water supplying after drying on flexural strength of cement paste is investigated and some considerations are given examining the crack with an electron microscope. It is concluded that a great number of cracks which is about 0.01 mm wide are occurred deu to drying for 1 day under constant relative humidity(R.H.) 43%, and they reduce the tensile strength of the specimen about 1/3 times lower than that of a sound specimen. Water curing for about 3 hours after drying repairs the cracks and the frexural strength is almost recovered.

1. INTRODUCTION

In a number of investigations (Ref.1-4) of the influence of curing condition on concrete strength, it has become apparent that curing under drying atmosphere after moist curing greatly affects tensile strength of concrete. The change in the tensile strength subject to rapid drying is dependent on the type of testing method. In general, the tensile strength of dried-cured concrete become lower than continuously moist-cured one's under direct tensile test and flexural test. Conversely, spilitting tensile strength increases by drying. Regardless of the type of the test, the strength almost converges to continuously moist-cured one's with the passage of the drying period.

It can easily be surmised that the reason the strength changes by drying is related to the stress caused by surface shrinkage due to drying against internal restraint or the minute cracks as the results of those. Then why does the strength recover as drying time goes on? Takeda explains it in Ref.4 as follows: The restrained tensile stress around the surface reduces the direct tensile strength, and the relaxation by the creep recover the strength once reduced by drying. However, the above explanation cannot be accepted when considerable number of cracks arise at the surface, as the occurrence of the cracks relaxes the restraint stress.

This paper shows new experimental data on the influence of the curing condition on the tensile strength and gives some considerations for the reason the strength changes. The influence of water supplying after drying and reiteration of drying and wetting on the flexural strength of cement paste is newly investigated.

2. THE INFLUENCE OF WATER SUPPLYING AFTER DRYING ON FLEXURAL STRENGTH

The flexural test was carried out for the cement paste whose water-cement ratios were 30% and 50%. The specimen had square section of 4cm x 4cm. The type of the test was the flexural test subject to concentrated load and the testing span was 10cm. The tensile strength due to bending is the apparent tensile strength, which is the moment at the critical section devided by the section modulus of the specimen.

Testing schedule is illustrated in Fig.1. The test consists of two series, one, monotonous drying test and the other, three times drying and wetting reiterating test. The flexural strength of the specimens continuously cured in water, allowed to dry under R.H.=43% for 1 day after a certain period of water curing and cured again in water after drying for 1-24 hours, were examined. Testing ages were 5, 9 and 28 days, and the specimens tested at the same age under the same condition of curing were 3-6 in number.

Testing results are summarized in Fig.2. The void circles stand for all results on the flexural strength, and the mean values of them under the same

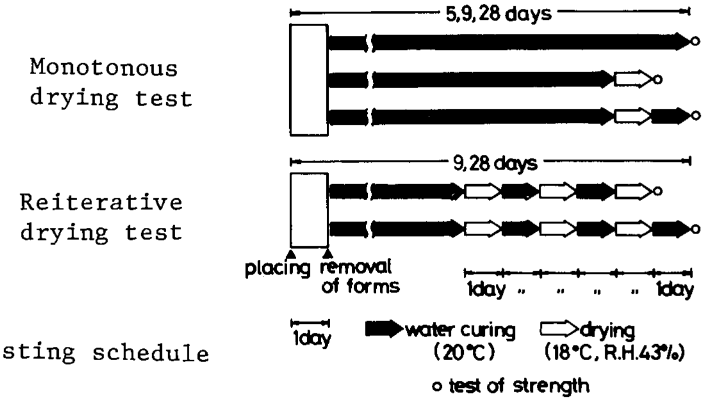


Fig.1 Testing schedule

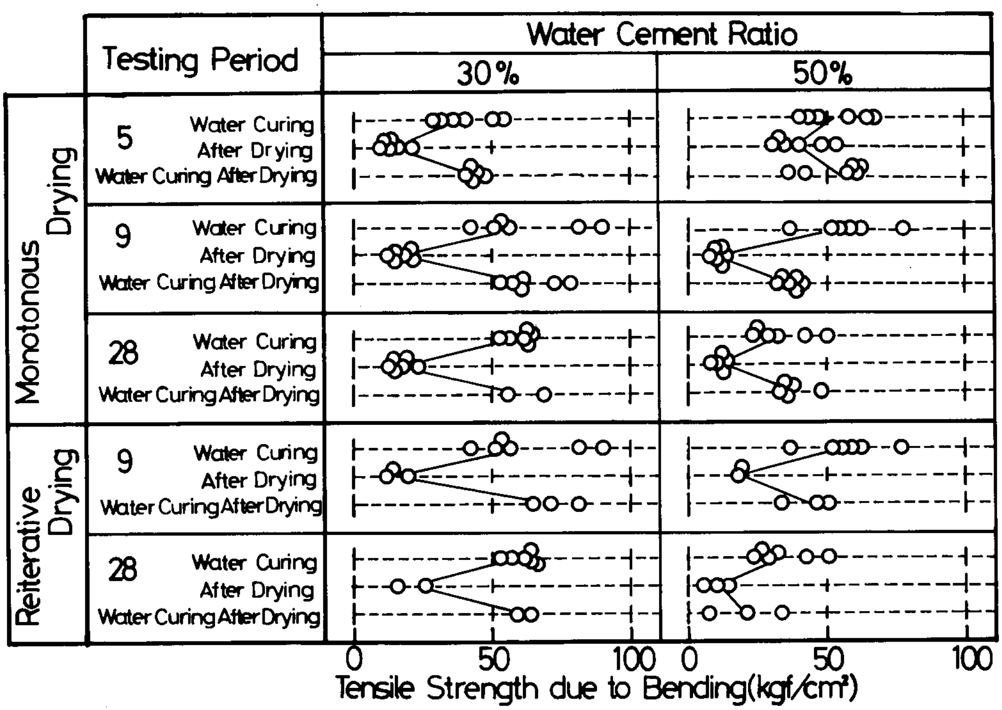


Fig.2 Summary of the testing results

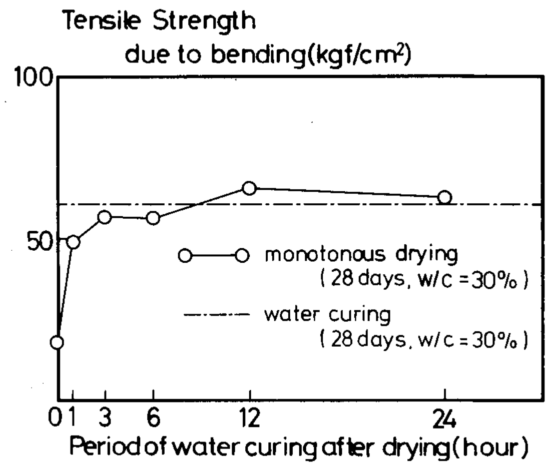


Fig.3 Relationship between tensile strength and period of water curing after drying

condition are connected with lines for each testing series. The strength of the specimens cured in water, allowed to dry and cured again in water for 24 hours after drying are described downward in turn. Broadly speaking, the strengthes of the specimens allowed to dry are reduced about 1/3 times lower than the one's continuously cured in water. The water curing for 24 hours recovers the flexural strength almost same as the one of the sound specimens except for the reiterative drying test for the specimens (W/C=50% and testing age: 28days.)

Figure 3 shows the relationship between flexural strength and period of water curing after drying of the typical series of the test (monotonous drying, W/C=30% and testing age: 28days.) The void circles stand for the mean values of the test data. It is known that the tensile strength is almost recovered by the water curing for 3 hours after drying. Except for the reiterative drying test of the specimens (W/C=50% and testing age: 28 days,) similar results were obtained.

3. CRACK OBSERVATION AND DISCUSSION

Figure 4 shows the surface of the specimen whose W/C is 30%, cured in water until age of 26 days and dried for 1 day long. It was photographed just after wiped on a wet cloth. A great number of cracks due to drying shrinkage are observed. According to the microscopic examination, the width of them is about 0.01 mm at the surface and the depth of the end of the cracks from the surface amounts to 3-10 mm. If those cracks distribute perpendicular to the axis of the specimen and the frequency is two cracks per centi-meter in the axis, the normal strain at the surface reaches to 0.2%, which is almost equal to the ultimate strain of the cement paste whose W/C is 30% due to drying under R.H.= 40%. As for the specimen shown in Fig.4, the restraint stress at the surface must be relaxed almost perfectly. Therefore the main reason of the reduction of the strength will not be the restraint stress but the minute cracks caused by the drying shrinkage.

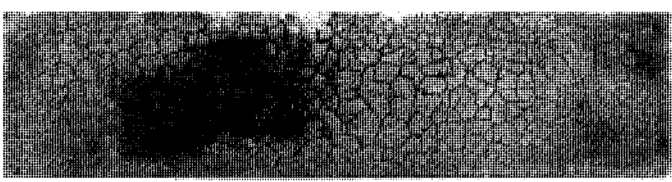


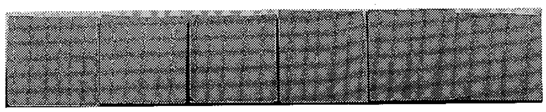
Fig.4 Surface of the specimen after drying

Broken sections of the specimens after the flexural test are shown in Fig.5 for all series of the test. Six sections are described for each testing series. The leftmost one stands for the specimen dried for 1 day. The others are the specimens cured again in water after drying for 1, 3, 6, 12 and 24 hours in turn. The surface of the broken sections of the specimen tested just after drying is very rough as shown in Fig.5 because of the existence of the minute cracks previously mentioned. The roughness of the sections of the dried specimens is affected by the testing age and water-cement ratio of the specimen, as the stiffness and the water diffusivity, which are the important factors for the restraint stress at the surface, change according to the age and W/C of the specimen.

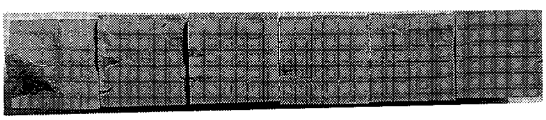
The surface becomes smooth according to the period of the water curing after drying except for the reiterative testing specimen in which the recuperation of the strength was not observed. The above results mean that the specimens cured in water for a certain period after drying did not failed at the cracks initiated while the specimen was allowed to dry. The water supplying obviously has some influences on a property of the cracks, and the tensile stress can be transmitted across the surface of the crack occurred during the dried curing.

The authors reason that the added hydration reaction due to water supplying will repair the cracks. It is commonly said that non-hydrated cement particles remain in completely hydratd cement matrix, as some cement particles become enclosed with the products of the hydration and disturbed from contacting with water ultimately. There is every probability that the crack due to drying shrinkage exposes the non-hydrated cement particles again to the field of the hydration. It is thought that the water curing for a few hours will be enough long for the specimen to exhibit the sufficient tensile strength, as the hydration is necessary only for connecting two solids with enough strength across the crack surface.

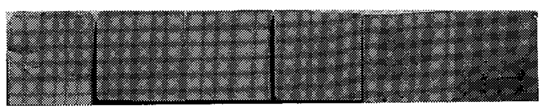
W/C=30%, age: 5 days



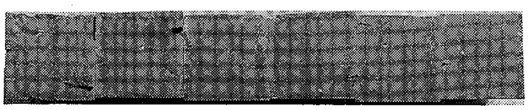
W/C=50%, age: 5 days



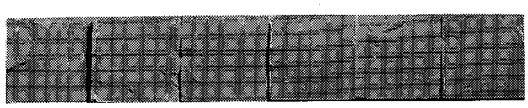
W/C=30%, age: 9 days



W/C=50%, age: 9 days

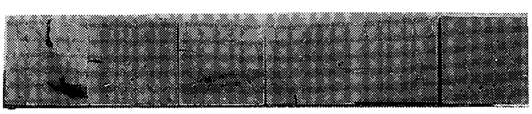


W/C=30%, age: 28 days

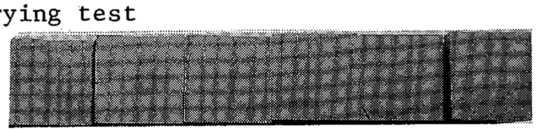


W/C=50%, age: 28 days

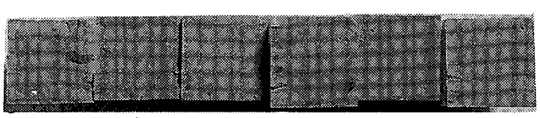
Monotonous drying test



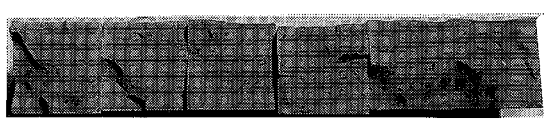
W/C=30%, age: 9 days



W/C=50%, age: 9 days



W/C=30%, age: 28 days



W/C=50%, age: 28 days

Reiterative drying test

Fig.5 Broken sections of the specimens

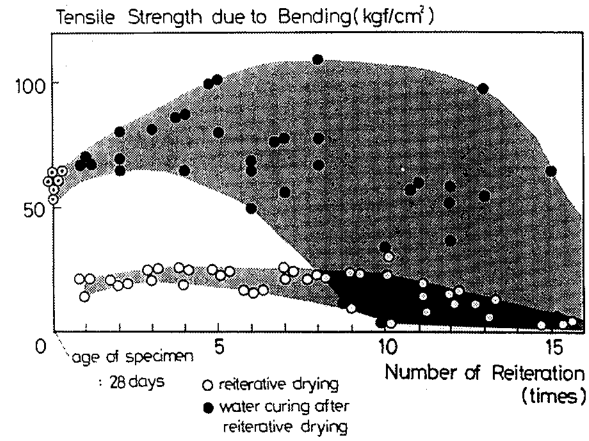


Fig.6 Relationship between tensile strength and number of iteration

Figure 6 shows the results of the additional reiterative drying test. The water-cement ratio was 30%. The specimens were dried and wetted again and again after initial water curing for 28 days. The drying and wetting period were 18 and 6 hours respectively. The relative humidity of the room in which the specimens were dried was also 43%. The weight of the specimens after one cycle of drying and wetting was approximately constant in spite of the number of the iteration. The relationship between the tensile strength and the number of the iteration is described in Fig.6. The increase of the number of the iteration has a tendency not to recuperate the tensile strength. Those phenomena can be explained, if the cause of the strength recuperation is the repairing of the crack by the hydration. Hence, the iteration of drying and wetting exhausts the non-hydrated cement. The recuperation of the strength would not be observed in the reiterative test above mentioned by the similar reason. The ratio of the weight of the combined water to the weight of the cement initially mixed near the surface (the depth was about 5 mm from the

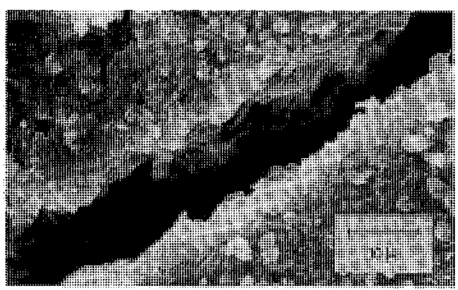


Fig.7 Crack configuration just after drying

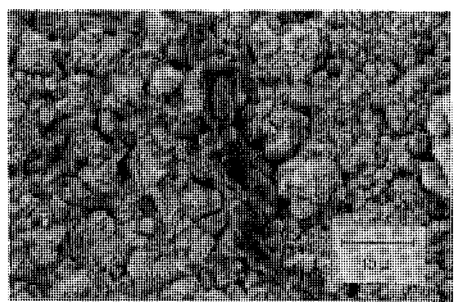


Fig.8 Crack configuration after water curing

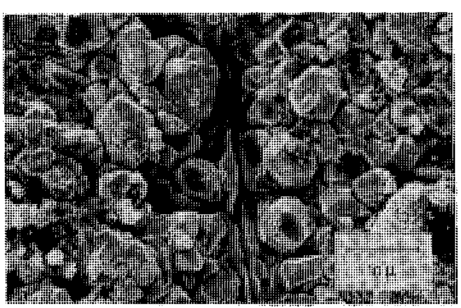


Fig.9 Crack configuration after water curing

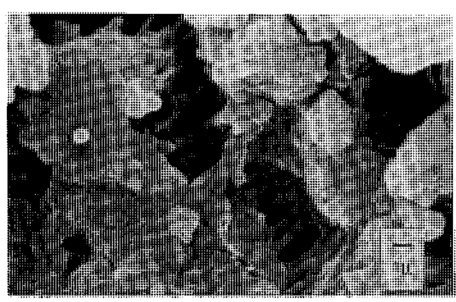


Fig.10 Crack configuration after water curing

surface) was measured in the experiment. It changed from about 15% at the start of the iteration to about 16% at the end of 20 times of the iteration.

Several typical results of the examination of the cracks with an electron microscope are described in Figs.7-10. Figure 7 shows the configuration of the crack of the specimen after drying and the other figures show the ones cured in water after drying. Fewer cracks could be observed at the surface of the specimen cured again in water, compared with the one just after drying. The crack width of the water cured specimens was also narrower, because the cement paste which once shrunk by drying expanded again by the absorption of water. The various shaped crystals of the products by the hydration, which were not observed at all in the crack of the dried specimen, were distributed just as they fill up the gap, as shown in Figs.8-10.

4. CONCLUSIONS

The conclusions are summarized as follows.

(1) The drying after a certain period of water curing reduces flexural strength of cement paste about 1/3 times lower than that of a sound one.

(2) For a few hours water curing after drying recuperates flexural strength of cement paste as high as that of a sound one.

(3) The increase of number of drying and wetting reiteration has a tendency not to recuperate frexural strength.

(4) The reason of the reduction of flexural strength deu to drying is the exsistence of minute cracks due to drying shrinkage. Water supplying obviously has some influences on the performance of stress-transmitting across the surface of the crack.

REFERENCES

1. Hanson, J. A. 1968. Effect of Curing and Drying Enviroments on Splitting Tensile Strength of Concrete. ACI Journal Vol.65 No.7: 535-543
2. Johnston, C. D. and Sidwell, E. H. 1969. Influence of Drying on Strength of Concrete Specimen. ACI Journal Vol.66 No.9 :748-755
3. Raphael, J. M. 1984. Tensile Strength of Concrete. ACI Journal Vol.81 No.2: 158-165
4. Takeda, Y., Sato, Y. and Nagamatsu, S. 1989. Influence of Drying on Tensile Strength of Concrete Specimen. CAJ Proceedings of cement & concrete No.4: 334-339