Study of Precast Concrete under Different Curing Conditions

Jiayang Zhang, Guozhong Lu, and Zhenlei Guo
Shijingshan district, Beijing, China
Email:zhangjiayang@bbma.com.cn

Abstract. The strength and durability of precast concrete under different curing conditions were studied from the actual production of precast reinforced concrete member. The results showed that the early strength of concrete at room temperature for 24h, standard steaming for 12h and constant temperature steaming for 12h could all meet the concrete form removal requirements, but the concrete strength by constant temperature steaming for 7d, 28h was lower than room temperature curing and standard steaming. The durability of concrete in steam curing was lower than that in room temperature.

1. Introduction
Prefabricated construction has been attaching more and more attention from the industry for its fast construction speed, labor saving and guaranteed quality. At present, with the rapid development of prefabricated construction in China, precast concrete structures have been used in more and more engineering projects. Precast concrete members are mostly produced in factories. In order to improve the production efficiency, precast members are often cured by steaming in curing kilns so that the early strength of concrete can be improved and the form removal strength achieved. In the production of precast concrete members, the following methods are often used for concrete curing, including room temperature curing, constant temperature steaming and standard steaming, which are selected according to different requirements. In this paper, the influence of different curing conditions on concrete performance is tested and studied, aiming at providing some technical support for the actual production of precast concrete members.

2. Test Materials

2.1 Cement
The PIII42.5R cement manufactured by Jidong Cement Luanxian Co., Ltd. was used.

| Item                   | Specific surface area (cm²/g) | Normal consistency | Initial setting time (min) | Final setting time (min) | Stability | Compressive strength | Flexural strength |
|------------------------|------------------------------|--------------------|---------------------------|--------------------------|-----------|---------------------|-------------------|
| Result                 | 390                          | 31%                | 132                       | 192                      | Qualified | 41.2                | 58.2              |

2.2 Sand and Stone
The manufactured sand used by Rengezhuang and the crushed stones in Yutian, Tangshan were used. The fineness modulus of medium sand is 2.6, the silt content is 2.1%, and the content of clay lump is
1.7%. The silt content of crushed stone is 0.5%, the content of clay lump is 0.1%, the content of elongated and flaky particles is 2.9%, and the crushing index is 7%.

2.3 Fly Ash
The Grade II fly ash of Tangshan Linde Trading Co., Ltd. was used, with fineness of 19.5%, water requirement ratio of 102% and loss on ignition of 4.7%.

2.4 Admixture
The polycarboxylate high performance water reducer of Jinyu Science and Technology (Tangshan) Co., Ltd. was used, and a test on the compatibility of cementitious materials and the admixtures was carried out.

3. Test Scheme
Based on the early strength of cement, fly ash was used as micro-aggregate for filling, the mix ratio was calculated by volume method, the concrete slump was designed to be 140-160 mm, and the curing conditions were designed at room temperature curing for 24h, constant temperature steaming for 12h and standard steaming for 12h. After undergoing different curing conditions, the standard curing method was used to continue curing to 28d. The test scheme was designed based on the common strength C30 and C35 of precast concrete members, and the mix ratio design and test were carried out based on the form removal strength up to 75% of the design strength. See Table 2 for the test design.

| Name of PC member          | Concrete strength grade of PC member | Target slump mm | Standard value of form removal strength MPa | Test value of form removal strength MPa |
|----------------------------|--------------------------------------|-----------------|--------------------------------------------|----------------------------------------|
| Composite slab, stair      | C30                                  | 140–160         | >22.5                                      | >28.3                                  |
| In shear wall, exterior wall panel | C35                                  | 140–160         | >26.2                                      | >32.0                                  |

4. Test Results and Analysis

4.1 Influence of Different Curing Conditions on Concrete Strength
The fly ash content of concrete with different strength was determined through preliminary tests. On the basis of improving the workability of concrete, the amount of cement used was reduced to cut down the production cost of PC members, and the test mix ratio was designed as per different concrete strength. See Table 3.

| Grade | Water | Cement | Fly ash | Sand | Stone | Admixture |
|-------|-------|--------|---------|------|-------|-----------|
| C30   | 145   | 310    | 80      | 860  | 1050  | 11.5      |
| C35   | 145   | 340    | 60      | 860  | 1050  | 12.0      |

Different curing conditions were designed as follow: (1) Room temperature curing: temperature 25°C, humidity 58%; removal of forms after 24h; (2) Constant temperature steaming: setting for 2h, curing at constant temperature of 55°C for 8h and cooling for 2h; humidity 75%; removal of forms after 12h; (3) Standard steaming: setting for 2h, heating up for 2h to 55°C, curing at constant temperature of 55°C for 6h, and cooling for 2h; humidity 75%; removal of forms after 12h. The concrete was cured under different curing conditions, and the influence of the compressive strength of concrete at 12h (24h for room temperature curing), 7d and 28d was analyzed. The compressive strength of concrete under different curing conditions is shown in Table 4.
Table 4 Compressive strength of concrete under different curing conditions

| Grade | Form removal strength MPa | Room temperature curing MPa | Constant temperature steaming MPa | Standard steaming MPa |
|-------|---------------------------|-----------------------------|-----------------------------------|-----------------------|
|       |                           | 24h | 7d   | 28d | 12h | 7d | 28d | 12h | 7d | 28d |
| C30   | 28.3                      | 45.9 | 49.1 | 28.8 | 40.1 | 47.7 | 31.2 | 44.9 | 50.8 |
| C35   | 32.0                      | 53.8 | 56.1 | 34.7 | 43.2 | 48.8 | 35.5 | 46.8 | 54.3 |

It can be seen from Table 4 that the concrete strength after room temperature curing for 24h, constant temperature steaming for 12h and standard steaming for 12h can meet the requirements for trial mix of form removal strength, and the strength at 28d can meet the acceptance evaluation criteria. Therefore, the compressive strength of concrete under three different curing conditions can meet the requirements of form removal strength.

Figure 1. Comprehensive strength of C30 concrete

As can be seen from Figure 1, the compressive strength of C30 concrete cured at room temperature is less than that under constant temperature steaming and standard steaming, showing that steaming can obviously shorten the curing time of concrete and improve the early strength of concrete. The strength at 24h of natural curing can be reached by steaming for 12h. Standard conditions are carried out after room temperature curing for 24h, constant temperature steaming for 12h and standard steaming for 12h. When the concrete is cured under standard conditions for 7d, it can be found that the strength of concrete cured at room temperature for 7d increases quickly, and that under constant temperature steaming and standard steaming increases more slowly. When the concrete is cured under standard curing for 28d, the strength of concrete cured at room temperature increases very little, almost equal to that at 7d, while the strength of concrete under constant temperature steaming and standard steaming increases steadily at 28 d, and the strength of concrete under standard steaming is higher than that under constant temperature steaming at 12h, 7d and 28d.
Figure 2. Comprehensive Strength of C35 Concrete

As can be seen from Figure 2, the compressive strength of C35 concrete cured at room temperature is higher than that under constant temperature steaming and standard steaming, showing that the early strength of C35 concrete under room temperature curing, constant temperature steaming and standard steaming is not much different after the amount of cement used in cementitious materials is increased. The strength at 24h of natural curing can be reached by steaming for 12h. Standard conditions are carried out after room temperature curing for 24h, constant temperature steaming for 12h and standard steaming for 12h. When the concrete is cured under standard conditions for 7d, it can be found that the strength of concrete cured at room temperature for 7d increases quickly, and that under constant temperature steaming and standard steaming increases more slowly, indicating that the hydration reaction can be accelerated in the early stage of concrete by steaming, but the overall strength is lower than that under room temperature curing at 7d. When the concrete is cured under standard conditions for 28d, the strength of concrete cured at room temperature increases very little, almost equal to the strength at 7d, showing the same law of increase as that of C30 concrete, while the strength of concrete under constant temperature steaming and standard steaming still increases steadily at 28d. The strength of concrete under standard steaming is higher than that under constant temperature steaming at 12h, 7d and 28d, and is close to the strength of concrete cured at room temperature at 28d. Thus, it can be known that the concrete strength at 28d does not differ much at the stages of room temperature curing and standard steaming that have a major influence on concrete strength, showing that different curing methods only affect the hydration speed but not the total amount of hydration products. However, constant temperature steaming has no “heating-up period”, and therefore has great influence on the strength of concrete.

4.2 Influence of Different Curing Conditions on Concrete Durability

The carbonation depth, chloride ion penetration resistance and shrinkage of precast concrete under room temperature curing (C30B) and standard steaming (C30R) were studied under different curing conditions. Standard steaming was carried out after room temperature curing for 24h and standard steaming for 12h, and a durability test was carried out. The test standards and classification standards followed GB/T 50082-2009 Standard for Test Methods of Long-term Performance and Durability of Ordinary Concrete and JGJ/T193-2009 Standard for Inspection and Assessment of Concrete Durability, respectively. See Section 5 for results.
Table 5. Durability of precast concrete

| Sample name | Item | Carbonation depth (mm) | Chloride ion penetration resistance (C) | Shrinkage |
|-------------|------|------------------------|----------------------------------------|-----------|
| C30B        | Test results | 3.9 | 1869 | 216.8×10⁻⁶ |
|             | Classification and requirements | T-IV | Q-III | —— |
| C30R        | Test results | 5.3 | 2458 | 277×10⁻⁶ |
|             | Classification | T-IV | Q-II | —— |

It can be seen from Table 5 that the carbonation depth, chloride ion penetration resistance and shrinkage of concrete under room temperature curing (C30B) and standard steaming (C30R) are basically consistent, and the durability indexes of standard steaming are slightly worse than those under room temperature curing. There is no unified index requirement for the durability of concrete materials in fabricated construction. The durability test data in this paper provides basis for high performance concrete used for fabricated construction or precast concrete used for buildings and structures with special requirements in the future.

5. Conclusion

(1) The strength of concrete can reach the designed form removal strength at room temperature curing for 24h, constant temperature steaming for 12h and standard steaming for 12h.
(2) The strength of concrete cured at room temperature increases quickly in 7d, while that under constant temperature steaming and standard steaming increases quickly in 12 hours.
(3) The more the cement in cementitious materials, the greater the impact of steaming on concrete strength.
(4) Standard steaming is better than constant temperature steaming. Precast concrete should be cured in the sequence of setting - heating-up - constant temperature curing - cooling in production.
(5) The carbonation depth, chloride ion penetration resistance and shrinkage of precast concrete under room temperature curing and standard steaming are basically consistent; however the durability index of standard steaming is slightly worse than that of normal temperature curing.

6. References

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