Advanced Materials Research Vols. 133-134 (2010) pp 985-990

doi:10.4028/www.scientific.net/AMR.133-134.985

On 4R Principle in the Rehabilitation of Concrete Historic Buildings

XIAO Jianzhuang[1,a], LI Wengui[1,b] and TAWANA M M[1,c]

[1]Department of Building Engineering, Tongji University, Shanghai, China
[a]jzx@tongji.edu.cn, [b]wengui.li1021@gmail.com, [c]xiums@yahoo.com

Abstract The 4R principle refers to reduce, reuse, recycle and regeneration, which should be implemented in the process of concrete treatment. In terms of the special micro-structural properties and self-repairing capacity, concrete is one kind of regenerative construction materials. Through proper handlings, self-repairing (crack close-up) of concrete cracks is possible in the concrete hydration damaged region. Due to the effect of heterogeneous nucleation and subsequent crystal growth of calcium hydroxide, a better bonding strength forms interlocking the new and old concrete interfaces. A proposal on the relationship between the self-repairing, regeneration function of concrete and the rehabilitation of historic buildings is suggested, this is based on the formed process of the bonding strength of the interfaces and the function on concrete repairing. Besides the constitution and features of the microstructure of concrete, the relationship between the micro-structure and the macro-mechanical property is also investigated in this paper.

Key words: Concrete, rehabilitation, micro-structure, reduce, reuse, recycle, regeneration

Introduction

Inheriting the outstanding historical and cultural heritage and carrying out repairing work excellently for modern concrete architecture is becoming more and more important. Rehabilitation techniques not only play an important role in promoting the protection of these cultural heritages but also play an important role in the protection and regeneration of historic buildings. The establishment of internal relations between rehabilitation of concrete historic buildings with reduce, reuse, recycle and regeneration (4R principle) appears to be very urgent and necessary.

The "Original true-type fix" approach should be followed in the repairing process of historic buildings (Hou 2006). In terms of repairing techniques and materials, the 4R principle should be implemented in concrete treatment of rehabilitation of concrete historic buildings. “Reduce” refers to preferring reinforcement to repair in the rehabilitation process of concrete historic buildings, with the aim of reducing waste concrete. “Reuse” refers to according to the requirements of bearing capacity and stiffness, using demolished concrete elements again (just simply shaping and furnishing them for the intended purpose) in the rehabilitation process, to avoid concrete elements becoming waste concrete prematurely as much as possible. “Recycle” refers to utilizing recycled coarse aggregates developing from demolished concrete (crushed concrete) elements to mix with other concrete ingredients to produce recycled concrete. Recycled concrete can also be used in historic buildings repairing (Xiao 2008). “Regeneration” refers to self-repairing function and renewing mechanism of concrete. For the special micro-mechanical properties and self-repairing possibility, concrete can be regarded as one kind of regenerative material (Li et al. 1999, Xie et al. 2000, Mehta et al. 2006).

The Rehabilitation Principles of Historic Buildings

Historical style, repairing techniques, materials, etc. are not mutually isolated or mutually exclusive. In general, repairing techniques and materials used in rehabilitation of historical buildings should not change or destroy the status quo of the buildings. It is necessary to preserve the essence of architecture, considering the overall harmony of architectural style and sense of history. Furthermore, by using the materials similar with the original buildings, the preservations of historical style are available. As to the "Original true-type fix" approach in rehabilitation of historical buildings, it is expected to demonstrate the authenticity of historical buildings, thus to preserve the architectural historical value. In the rehabilitation of the concrete historic buildings, the 4R principle should be followed progressively (as shown in Fig.1).

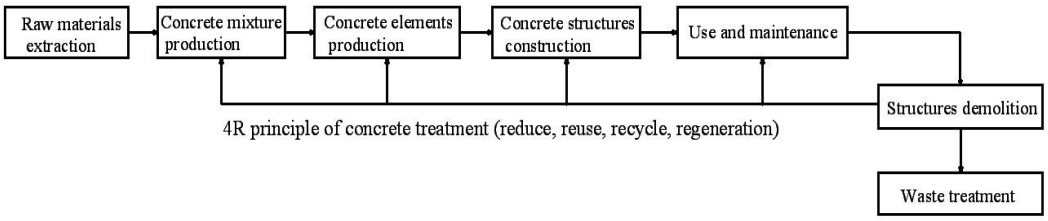

Figure 1: 4R principle in rehabilitation of concrete historic buildings

Rule of Reduce in Rehabilitation

In the rehabilitation process of historic buildings, it is necessary to reduce concrete construction waste. If the concrete elements with damaged cracks can meet the load carrying capacity requirement, in terms of the micro-structural properties of concrete, the cracks can be self-healed under treatment by fresh cement paste and interfacial agents (Aggelis and Shiotani 2007). Thus, the concrete construction waste produced by repair work can be diminished correspondingly (Fig.2).

On the other hand, if the load carrying capacity can not meet the design requirements, the concrete elements should be reinforced rather than repaired as much as possible. Normally, concrete beams and plates are strengthened by bonding steel plates, while concrete columns by wrapping steel or FRP fiber.

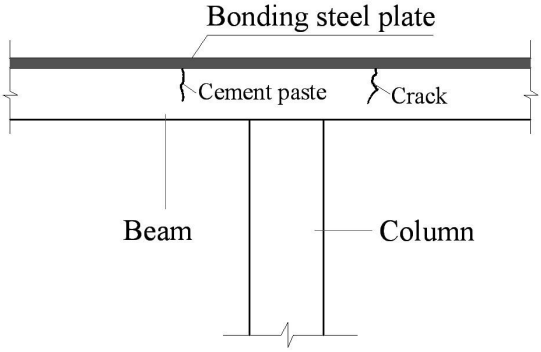

Figure 2: Crack repairing and beam strengthened by bonding steel plate

Rule of Reuse in Rehabilitation

In rehabilitation process, according to the load carrying capacity and stiffness requirements, original concrete elements (e.g. beam, slab and column), demolished form historical buildings, should be further used again necessarily. Thus, the overall harmony of historical style can be maintained

reasonably as shown in Fig.3. When the surfaces of damaged concrete are chiseled, cleaned and polished, concrete which was part of cover but removed in the process of furnishing should be replaced by new concrete mixed with Portland cement, fine sand and recycled coarse aggregates as crushed limestone (Alfarabi et al. 2006). The load bearing capacity and stiffness of concrete elements can be enhanced by increasing cross-sectional reinforcements. As a result, much less new concrete need to be cast in rehabilitation process.

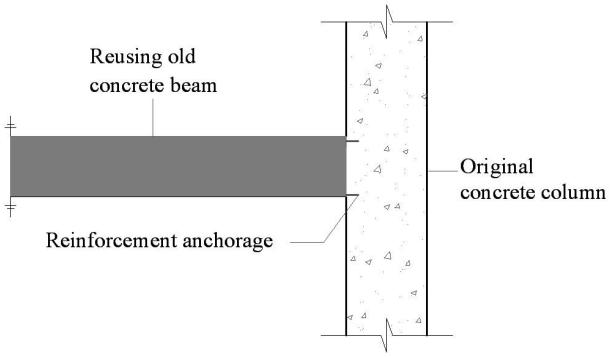

Figure 3: Reuse of original demolished concrete beam

Rule of Recycle in Rehabilitation

Recycled aggregate concrete is made from recycled coarse aggregates which are produced from crushing waste concrete, replacing some or all of the natural aggregates (Fig.4). In this way, construction and demolition (C&D) concrete waste could be recycled for manufacture of new construction products. At the same time, less natural resources and fuels are consumed and less green house gases are emitted. As a result, adopting recycled aggregate concrete techniques can make the rehabilitation process to be of great value to the environmental protection and energy-efficient. In the rehabilitation process, recycled concrete can be cast in the additional fulcrum reinforcement, as shown in Fig.5.

On the other hand, recycled fine aggregate can be utilized to produce concrete blocks, paving bricks and lattice bricks. All the building materials are expected to be used directly in the rehabilitation. Crushed waste concrete can also be used as the base layer cushion in road construction. To optimize the use of the demolished metal materials, they can not be utilized directly in rehabilitation, the re-melted and forging processing should be carried out accordingly.

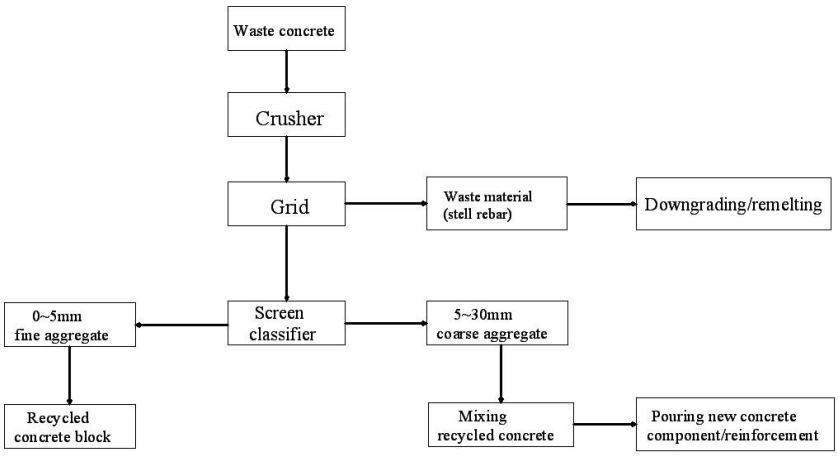

Figure 4: Recycling concrete waste

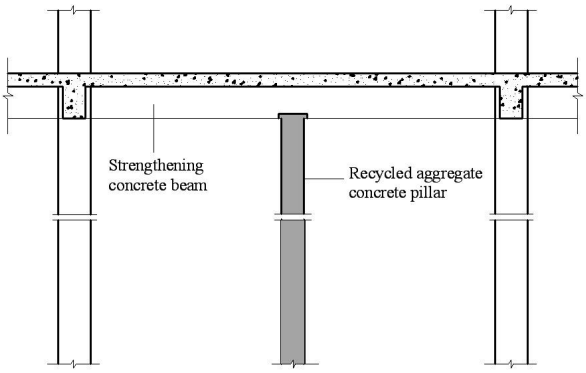

Figure 5: Additional fulcrum reinforcement

Idea of Regeneration in Rehabilitation

The concept regeneration ability, brought forward based on biomedicine, means the ability to recreate a portion of lost or damaged tissues, organs and limbs. Concrete can be considered as one kind of composite materials. The regeneration of concrete means the regeneration and renewing mechanism. When the concrete material encounters some damage, it can self-healed or even enhance the mechanism performance of the original material.

Crack Self-healing in Regeneration. Self-healing of damaged cracks that is concerned in concrete regeneration refers mainly to the healing process, aiming at guaranteeing the structural integrity and durability by patch repairing in the damaged zones (Li and Tang et al. 2004). Injection of cement paste or permeable crystallization materials can be introduced in the self-repairing function of damaged cracks. Micro-mechanism characteristics of hydration products provide a better insight into self-repairing of damaged concrete cracks in the regeneration process. The mechanical strength and durability increase as new ettringite and calcium hydroxide crystals enter into the pore space of damaged concrete cracks by capillary action. C-S-H gels and whisker-like ettringite crystals intertwine together, resulting in a mechanical bonding strength along interfaces which makes the concrete self-heal as a whole, as shown in Fig.6.

(a) Damage and concrete cracks *(b) Self-healed concrete cracks*

Figure 6: Self-healing of concrete crack

Bonding Regeneration along Interfaces. Bonding regeneration ability between new and old concrete contributes to the structural integrity and durability for concrete historical builds. Before new concrete to be cast to old concrete, it is essential to apply some treatments (e.g. chiseling, cleaning and polishing or rather furnishing) to the old surface (Zhao et al. 2001). Within the interfaces region, calcium hydroxide gels, ettringite and flake-like C-S-H crystals are produced after further hydration. Thus, bonding strength can be obtained by hydration products which intertwine together as shown in Fig.7. For interfaces between new and old concrete, the transition layers can be divided into three thin layers (permeability layers, strong effect layer and weak effect layer). In

the interfaces region, the bonding strength of interfaces is related to the shapes and distributions of hydration crystals.

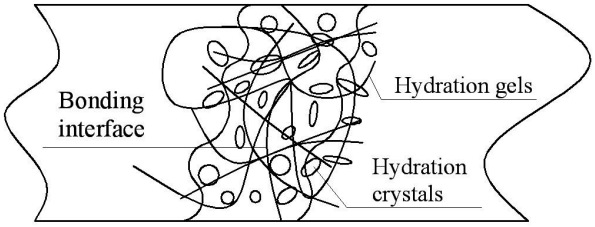

Figure 7: Bonding regeneration along interfaces between new and old concrete

Discussions and Conclusions

In the rehabilitation process of concrete historical buildings, 4R principle (Reduce, Reuse, Recycle and Regeneration) is one of the sustainable development strategies of the world, playing a significant role in conserving the sources of natural aggregates and reducing the cost of concrete waste treatment, prior to disposal.

- "Reduce" refers to preferring reinforcement to repair as much as possible in rehabilitation of concrete historic building, in order to limit the amount of concrete waste during renovations and maintenance work.
- "Reuse" refers to adopting demolished concrete elements again in rehabilitation for concrete historic building in accordance with the design requirements like load bearing capacity and stiffness, aiming at preventing concrete elements from falling into construction waste.
- "Recycle" refers to utilizing recycled coarse aggregates developing from demolished concrete elements to mix recycled concrete by replacing the natural aggregates partially or completely.
- "Regeneration" refers to self-repairing function and renewing mechanism of concrete. For the special micro-mechanical properties and self-repairing capacity, concrete can be regarded as one kind of regenerative materials. Based on the regeneration function of concrete, damaged cracks can be self-healed by adherence of new hydration crystals.

Acknowledgements

The present work was sponsored by the New Century Excellent Talents in Ministry of Education Project (NCET-06-0383), as well as the National Key Technology R&D Program of China (2008BAK48B03).

References

[1] Aggelis, D G, and Shiotani, T (2007). "Repair evaluation of concrete using surface and through-transmission wave measurements ." *Cement & Concrete Composites*, 29, 700-711.

[2] Alfarabi, S, Muhammad, K, and Ahmad, S (2006). "Behavior of patch repair of axially loaded reinforced concrete beams." *Cement & Concrete Composites,* 28, 734-741.(in Chinese)

[3] Hou, J (2006). "Techniques for conservation and restoration of historic buildings in Shanghai". *Time+Architecture.,* 02, 58-61.

[4] Li, G, Xie H, and Xiong, G (1999). "The relationship between micro-structure of repaired section and macro-mechanical properties of concrete." *Concrete.*, 6, 13-18.

[5] Li, H, Tang, C, and Zeng, S (2004). "Research on self-healing of concrete cracks," *Journal of Wuhan University of Technology*, 26(3), 27-29.

[6] Mehta, PK, and Monteiro, P JM (2006). "*Concrete Microstructure, Properties and Materials*." 3rd ed. Beijing, China: China Electric Power Press.

[7] Xiao, J (2008) "*Recycled Concrete*". 1st ed., Beijing, China: Building Industry Press.

[8] Xie, H, Li, G, and Xiong, G (2000). "Micro-structure and mechanism of forming bonding forces on interface between young and old concrete". in 9*th Annual Conference Proceedings on Engineering Safety and Durability.* Rep. 00-05.

[9] Zhao, Z, Zhao, G, and Liu, J (2001). "Experimental study on adhesive tensile performance of young on old concrete," *Journal of Building Structures*, 22(2), 51-56.