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CAST-IN-PLACE ARCHITECTONIC CONCRETE IN SOUTH KOREA: METHODS AND SPECIFICATIONS

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ABSTRACT

With its low environmental impact, availability, cost-effectiveness and versatility, exposed concrete became the first construction material choice for Korean architects. The French embassy in Seoul, designed by Kim Chung-Up and completed in 1962, is the first Korean example of concrete use in the country. Concrete marked a turning point in the contemporary Korean architecture by its design and its material properties.

To express the originality and quality of exposed concrete and describe its architectonic texture, the processes of placing and finishing have to be performed before and after pouring the concrete in the vertical formwork. The lack of fulfilling these requirements usually results in a low quality surface output.

In this paper, we review the main exposed concrete pathologies, present a detailed quality control process and analyze the actual South Korean exposed concrete cast-in-place recommendations.

Key words: Exposed concrete, Tadao Ando, Korean architecture, Formwork, Brutalist architecture, Concrete pathologies, Architectonic concrete.

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1. INTRODUCTION

Used for its global availability, cost-effectiveness and free-form plasticity, concrete becomes the first global construction material choice since World War II [1]. With the rapid Asian economic growth countries adopted quickly concrete as a substitute to wood [1, 2], the traditional Asian construction material. It is perceived as a modern construction material that reflects the modernity of the economic development of these modern contemporary industrialized countries [3]. However, the lack of adequate knowledge of design specifications and construction executions usually may lead to water infiltration

through the exposed concrete; thus the rebar deterioration affecting and surface imperfections affecting the structure durability [4]. To obtain a high structural performance, waterproofing with the desired aesthetical finish, architects, engineers and builders need to work in a collaborated team.

In this article, we focus on the concrete mix design characteristics, different formworks installation and in situ concrete placement factors that affect directly the improvement of the aesthetical appearance and the durability of the architectural concrete in Korea.

2. EXPOSED CONCRETE IN KOREA

Architectonic concrete use flourished from 1950s to the 1970s in western countries under the brutalist movement style [4]. The name derives directly from the French word “béton brut” used by Le Corbusier to describe the use of the concrete as raw material with the absence of ornaments [5].

Its expansion in Korea at that time was seen as a return to realism after the disenchantment with modernist ideals [6]. Exposed concrete became the favorite choice for Korean architects because it allowed new aesthetic choices in terms of forms and spaces.

The lack of Korean architectural expressionism due to construction material shortage from one side, and exposed concrete invisibility to the critical eye from another side, prompted Korean architects to use architectonic concrete [6].

The French embassy in Seoul, designed by Kim Chung-Up completed in 1962, is one of the first Korean examples of exposed concrete use in the country [7]. It marked a turning point in the contemporary Korean architecture by its design and its material expression.

3. GLOSS LEVEL MEASUREMENTS FOR DIFFERENT EXPOSED CONCRETE TYPES

Jeong and Lee (2012) published an experimental study on quality control standards of exposed concrete in construction in the Korea Journal of Construction Engineering and Management [8]; in their paper they presented different glossiness levels measurements (shiny appearance of concrete surface). They used different formworks that are currently available in the Korean market with five different binding materials proportions to determine the relationships between the gloss levels of the exposed concrete surface, the moulds and the concrete mix design [8].

Figure 1 represents the result of the experiment with seven formworks where it is shown that Euro-Form, Phenolic film faced shuttering plywood, Larch fancy plywood and Steel formworks are within a limit of less than 10 Gloss Units (GU). Regardless of the type of the binding materials proportions, the surface gloss quality is almost constant.

On the other hand, PET film faced plywood, Urethane coated plywood, and Plastic formworks glossiness levels vary from more than 25GU degrees to less than 45GU degrees depending of the bonding variation amounts. In fact, we can see that PET film faced plywood formwork has the highest gloss level, within 340kg/m³, the most common binding materials proportions available in Korea.

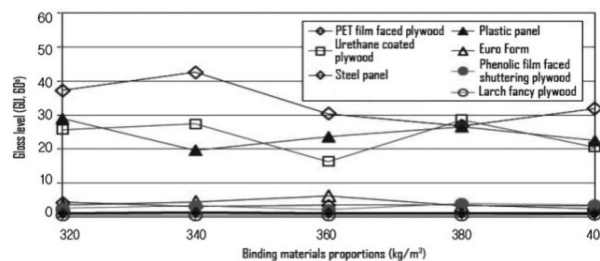








Figure 1 Exposed concrete gloss measurements [8]

4. COMMON FORMWORK SYSTEMS USED IN KOREA

Reinforced concrete is the favorite construction material Korean architects, especially for buildings with less than six floors and a total floor area $\leq 1000\text{m}^2$. We distinguish the use of three formwork types: Euro-Form, PET film faced plywood and Larch board. The choice of the formwork type depends on the desired external finish of the façade (table 1).

Table 1. Most used formwork in Korea

	Euro-Form	PET plywood	Larch board
Size (mm)	600x1200	910x1820	100x3600
Surface quality	Rough	Glossy	Wood-grain texture
Model			
Exposed concrete surface			
Number of use	10-15 times	1 time	1 time
Price (US\$/unit)	20.00	17.16	6.50

4.1. EURO-FORM

A coated plywood panel mounted on a steel frame, first selected choice for contractors because its low-cost and reusability. However, due to the excessive reuse the concrete skin generated is relatively rough at the same time the Form-Tie system joining the panels together generates a visible skin-joints on the concrete surface. External finishing materials are used to hide these façade imperfections.

4.2. PET FILM FACED PLYWOOD

Exposed concrete panels are widely used in building construction due to set up easiness and the high gloss level of the surface generated. Assembled with “D” Form-Tie system (steel bolt and a plastic cone).

The circular cones are mounted horizontally into two columns and three rows, from top to bottom symmetrically with six large bolts. The Forms-Ties are installed in the middle of the formwork rather than the edge, and the joints generated between the forms are usually between 2mm to 3mm. The result is a combination of regular conic holes with thin linear joints of the surface. It must be used not more than one time in order to get a high glossy concrete surface.

4.3. LARCH BOARD

Used only when the wooden texture is desired, the standard size of the wooden plank is between 100mm and 150mm large with 3600mm length.

Two methods are used for the installation:

- Place the Larch board on the Euro-Form formwork (fig. 2).
- Place the Larch board on top of plain plywood.

The difference between the two methods is the resulted form and shape of the Form-Tie, or the conic holes after the consolidation. For a better surface texture result, planks are used only once.

Korean architects generally adopt two different methods to generate an architectonic concrete façade; however, Euro-Form is still the best choice for erecting fast concrete walls that are supposed to be covered. Korean manpower is much more familiar with the Euro-Form system rather than other systems which result in a low-cost for the end of the project.

The use of release agent on timber formwork timber and plywood boards and is fundamental as well, for preventing any concrete paste water absorption. It helps the air seeping trapped between the concrete skin and the formwork panels.



Figure 2: Larch boards mounted on Euro-Form panels

5. CONCRETE MIX DESIGN

The mix design is the procedure for the calculation of the concrete composition (in terms of amount of cement, water and aggregates per m^3 of concrete), taking into consideration three factors [9]:

- Engineering properties of the hardened material (mechanical strength, elastic modulus, shrinkage, creep, durability, etc.) as they result from the project requirements;
- Execution requirements (workability, site organization, concreting, etc.);
- Materials availability (type of cement, aggregates and additives).

According to Jeong and Lee (2012), the ideal exposed fresh concrete mix design in the remicon truck is shown in Table 2.

Table 2 Ideal ready-mix concrete remicon truck components according to Jeong et al. [8]

Binder (kg/m^3)	Water (kg/m^3)	Slump (mm)	Compaction Time (sec.)
360~380	175	150 - 180	20

For small-scale buildings, it is quite uncommon to request personalized remicon truck components due to the additional costs. Nevertheless, in the region of Busan it is possible to specify the compressive strength which is set generally at 24MPa, and the slump value of 170mm (Table 3 and 4).

Table 3 Ready-mix concrete specifications: the case of Busan region [10]

Material	Cement	Admixture	Water	Fine aggregate	Coarse aggregate
Amount (kg/m ³)	338	2	168	890	928
	Total binders = 340				

Table 4 Ready-mix concrete specifications: the case of Busan region [10]

	Coarse aggregate (mm)	Compressive strength (MPa)	Slump (mm)	Cement type
Designation	25	24	150	Portland cement type I Blast furnace slag cement type II

6. EXPOSED CONCRETE EXECUTION PATHOLOGIES

At the moment of formwork removal, visible exposed-concrete pathologies can be seen. Most of the time the fault is given to the concrete itself defining it as a bad concrete quality which can result of a conflict between the construction actors: the architect, the developer and the construction company.

In many research papers [8,11, 12], authors limit the exposed-concrete aesthetical quality only to the formwork choices and quality, or to the concrete mixtures and additives; however most of the time, this aesthetical quality is not achieved due to a bad concrete working process. We will define the most common aesthetical pathologies in the followings:

6.1. BUGHOLES

One of the most visible pathologies which are seen as a series of bubbles with various sizes distributed over a part or the whole concrete surface and formed during placing and compacting concrete [4, 13].

The main cause of these bubbles is the presence of entrapped air between the concrete and the internal mold skin. Hammering on the exterior of the panels is not sufficient to eliminate it.

The right choice of the form-release agents has a great impact on the pitting effect, however, the compatibility with the formwork material, its density or a poor quality might be a cause for trapping air and not allowing it to seep up.

6.2. HONEYCOMBS

The most common pathology resulting from an important grout loss is manifested in the junctions or the lower parts of the boards/panels of the formwork [4, 13]. The concrete strength in these parts becomes weak due to its low consistency in mortar. A second cause could be the excessive segregation of the larger aggregates particles from the concrete when pouring it by a series of horizontal steel rebar while reaching the lowest part of the formwork, or due to poor vibration techniques.

6.3. GROUT LOSS

This phenomenon can be omnipresent in the case of using wooden boards [4, 13]. During the vibration, the grout flows out between the panels from the interstices forming small honeycombs. It can be manifested horizontally or vertically, sometimes in both directions. Repeatability could appear due the increase number of boards. The main cause of this defect is due to the deterioration of the timber boards or the joints (gaps) between them when assembled and not tightened or sealed well.

7. EXPOSED CONCRETE AND SUSTAINABILITY

As a high industrialized country, Korea needs a lot of energy to run all different sectors. According to Korea Energy Economics Institute, the total Korean energy consumption was more than 242 million toe (tone of oil equivalent) for 2016 [14].

In June 2016, the Ministry of Land, Infrastructure and Transport published an updated policy regarding the actual regulations on housing construction standards. The article 14-3 of the presidential decree n.27-216 of the 08th June 2016 states that any new housing construction of more than 500 households shall include an anti-condensation system [15]; however, the Korean construction code does not specify anything for the architectural concrete walls nor the formworks, except for general specifications of steel or wooden molds.

As the ninth world ranking in greenhouse gas emissions, Korea has emitted approximately 592 million tons of CO₂ during 2015 [16], the country is taking the challenge to reduce its greenhouse gas emission by 37% in all sectors by 2030 [17]. Knowing that buildings account for 45% of worldwide energy use and due to its massive growth, the construction sector can contribute effectively in the greenhouse gas mitigation process [18].

There are many researches on admixtures or waste use in the mix design to improve concrete performance and sustainability [19, 20, 21]. Concrete is a sustainable construction material [22], and it is only the process of cement production which is emitting a huge amount of CO₂ in the atmosphere [23]. According to the Korean building code, the insulation thickness range varies from 10 to 18,5cm for the Southern region depending on the building type and the thermal conductivity of the insulation material chosen [24]. In the other hand in Germany, the Passivhaus standard can achieve an energy consumptions reduction by 90% [25] by using a thermal insulation thickness which varies from 1,5 to 41cm depending on the construction material and the insulation material used [26]. In general cases, the passivhaus standard uses 3 times the insulations thickness used in Korea.

Typical insulation material thickness	Passivhaus	Korea
	30cm	10cm

8. CONSTRUCTION MANPOWER AND ARCHITECTURAL QUALITY

According to the Korean Statistical Information Service website, there are currently more than 1,5 million workers in the construction industry [27]. More than 265000 construction permits were granted in 2015 by the Ministry of Land, Infrastructure and Transport for different kind of buildings [27]. An annual budget of approximately US\$6 million was allocated by the Korean government during 2015 for the free professional training in 12 different building sectors [28]. The 20 days traineeship took place in 8 certified centers spread over the country [29]. These centers are administered by the Construction Workers Mutual Aid Association.

The Korean construction sector is in full expansion and the government wants to absorb this jobless population class by inserting it in the construction market. In fact, the government has doubled the traineeship financial support for the trainees; 8000 individuals in 2015 in comparison with 4700 in 2014 [28]. By this move the government is looking forward to improve the construction manpower skills, improving as such the architectural quality output. In Italy, the Ministers Council approve a policy regarding the architectural quality in 2008, this came as a new perspective of European market openness [30], but there is no such policy in the Korean building code or legislation.

9. QUALITY MANAGEMENT PROCESS

The following Requirements should be applied to get a high exposed concrete quality:

1. Use a vibrator during concrete pouring and hammering with a millet at the formwork exterior skin will facilitate the uniform concrete filling in the molds.

2. Vibrate concrete after completing its casting for about 15 seconds with 1 meter of interval. However, both under and over vibrating can lead the mortar paste to submerge at the top surface resulting in honeycombs inside the fresh poured concrete.
3. Strike uniformly on the formwork with the wooden hammer.
4. Apply a construction joint of 20 millimeters for every elevated floor.
5. Allow sufficient time (usually around 3 days) for the concrete to gain strength before the removal of formwork. This step will depend on weather conditions: heat, cold and wind.

Additionally, many architects use combined formwork types to get different interior and/or exterior aesthetic concrete textures. Figure 3 shows a single family house, with exterior gloss and a wooden textured concrete skin.



Figure 3 A single family house with two different exposed concrete textures

10. EXPOSED CONCRETE FINISH AND RETOUCHING

Aesthetical surface defects such as bugholes, small chips, and crazing cracks should not have a negative impact on the integrity of the structural system of the buildings; these aesthetical defects can be fixed after the formworks removing.

It is very common in Korea that the structural works are done by construction companies who are not qualified in exposed concrete walls. They neglect it to get the advantages of, first, the easiness and quickness of rising the building and second, the low-cost labor because of the unqualified manpower. But Korean architects in these cases hire the services of exposed concrete façade specialists to make the exterior waterproofing and aesthetical finish.

The following are the main work to do after removing the formworks and curing:

- Surface cleaning
- Edges and corners cosmetics
- Form-Tie holes sealing

Cracks sealing (especially at the basement and/or first floor for indoor radon mitigation is really important, since Korea has an average concentration of 124Bq/m^3 [31].

Depending on the total surface area and the manpower skills, it can only be some retouching works or the whole facade resulting a fake-real cast-in-place exposed concrete.

To ensure a high surface quality it is necessary to anticipate in advance an extra budget for retouching and aesthetics.

11. CONCLUSION

The high quality vertical architectonic concrete is an excellent addition for a lasting design. It is worth the investment with a proper mounting of the formwork, an adequate use of release agents, and a suitable use of the vibrators and pumping during the placing process. The good skills of the workmanship are

also the basis of the whole process, because untrained manpower can cause serious imperfections notably in the structure durability integrity.

As a result of this research we recommend the following:

- Korean government should emphasize on the building code with a detailed exposed concrete specifications and requirements.
- Architects should borrow concrete sustainable solutions that are already in use in Europe.
- The manpower class should be trained for a high quality exposed concrete finish.

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