A TAILOR MADE CONCRETE SOLUTION FOR TUNNELLING

Olga Rio & Carlos Arciniegas

Summary

The development of tailor made materials by using a performance based approach are attracting research interest in different construction areas due to the advantages of having solutions that should perform according to the specified needs. If focus is put on concrete and on the fitness of its functional requirements, the rational procedure would be to state the required main structural, durability and execution indicators (PI) and subindicators (PSI), i.e. mechanical strength at different ages or service life age with no major maintenance or execution difficulties. This paper deals with the design and evaluation criteria undertaken to the production of a tailor made concrete solution in order to allow a new designed autonomous tunnelling machines using a movable formwork [1] to hold to this concrete lining and continue with the excavation in a continuous concreting process.

Keywords: Tunnelling, tailor-made concrete, pumpability, long last workability, fast setting time, early age high compressive strength, early age and structural high tension strength

1 Introduction

Existing standards, guidelines and regulations [1][3][4][5][6] governing concrete mix design can be grouped in general and specific ones. While some deal with sampling and testing, others prescribe or give provisions related to a) the concrete materials: cement, water, steel and aggregate types, b) the concrete mix proportions, mechanical strength, consistency, etc. This prescriptive approach can be considered traditional and as such, it is much easier to be followed and accepted by manufacturers, designers or construction companies due ensure quality. The main disadvantage of this approach is the difficulties arisen by using new materials, components or new design rules (the ones needed by new concept concretes) thus preventing innovation to be implemented due they follow a deemed-to-satisfy rules.

However, there is an increasing demand to incorporate into the current standards more advanced concepts related to concrete design [1][3][4], testing and control methods
and tools (Non destructive ones) [5][6], due the need to better foresee actual structural concrete performance for a determined purpose or its “fitness for use”.

In recent years different studies have been carried out to implement new (or to improve) underground construction technological processes which requires also the investigation on how manufacturing adaptable Concrete Solutions [7][8]. These studies following a performance-based approach (PBA) allow the definition of tailor made (or fitness to use) concrete solutions based on the functions the concrete to be fulfilled independently of the nature or characteristics of the material proportions or composition.

In present paper a proposal is presented that tries to be comprehensive by responding to the demand related to the introduction of performance parameters or functional indicators and that being suitable for quality control could also be applicable for verifying the mechanical as well as fresh state concrete on lab and for designing, following a most rational approach, the trial mix to be verify on site by using real scale tests.

The chosen parameters are those presented on Tab. 1 where also the proposed target values (defined on standards or by the contractor) and the suggested real scale tests to be designed are indicated. Concrete main fresh state characteristics (pumpability and mix age) are related mainly to the first part of the process while its behavior at the early age and hardened state has to be considered under structural issues. The machinery temperature generated by the movable formwork has to be considered as the curing process might affect mechanical and long term properties of the material also. The impossibility of using traditional reinforcement due to the process as well as the use of local aggregate (due to cost) must be considered also.

<table>
<thead>
<tr>
<th>Functional requirement</th>
<th>(PI)</th>
<th>(PSI)</th>
<th>Sampling &amp; Testing procedure (STP)</th>
<th>Compliance criteria and target value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumpsable over 1000 m²</td>
<td>Pumpability</td>
<td>Slump flow</td>
<td>EN 12350-2 [5]</td>
<td>ACI 304.2R [10] &gt; 50 mm</td>
<td>A closed-loop pumping circuit must be used as real scale test. (*) Pump line φ = 75mm, flow = 6 m³/h.</td>
</tr>
<tr>
<td>Properly mix after 4-6 h</td>
<td>Workability</td>
<td>Slump flow on time</td>
<td>EN 12350-2 [5]</td>
<td>ACI 304.2R [10] &gt; 50 after 4-6 h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanical strength</td>
<td>% of loos at 28d</td>
<td>EN 12390-3</td>
<td>%≤ f_c28/ f_c30 ≤ 10-15%</td>
<td></td>
</tr>
<tr>
<td>Suitable structural behaviour</td>
<td>Mechanical strength</td>
<td>Compressive strength</td>
<td>EN 12390-3 [6]</td>
<td>EN 12390-3 [6]</td>
<td>f_c &gt; 18-20 MPa 12h f_c &gt; 40 MPa 28d</td>
</tr>
<tr>
<td></td>
<td>Indirect tensile</td>
<td>EN 12390-6 [6]</td>
<td>EN 12390-6 [6]</td>
<td>f_t &gt; 3 MPa 12h f_t &gt; 8 MPa 28d</td>
<td></td>
</tr>
</tbody>
</table>
2 Materials selection and concrete proportioning

If traditional design had been considered, an equivalent $f_{c,28} = 183$ MPa must be adopted due to the tensile effect is the most unfavourable design criteria (see Error! Reference source not found.). Nevertheless as the use of local aggregates as well as low cost materials are mandatory only the first and third values (obtained by considering the equivalent 12hs $f_{c,30}$ compressive strength) have been considered for designing mixes.

<table>
<thead>
<tr>
<th>$f_{c,28}$</th>
<th>183 MPa</th>
<th>73 MPa</th>
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</thead>
<tbody>
<tr>
<td>40 MPa</td>
<td></td>
<td></td>
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</table>

Concrete mix initial proportions have been selected following general criteria for normal strength concrete, according to standards [3]. The amount of powder (particle size smaller than 0.063 mm, i.e. cement + silica fume + limestone powder) should be about 500-550 kg/m$^3$, the absolute volume of coarse aggregate between 0.30 to 0.36 m$^3$, the ratio between sand to mortar volume between 0.50 to 0.60 and the water to powder ratio between 0.95 to 1.05. Using these criteria, trial mixes were prepared and minor adjustments were made (only definite mixes main characteristics and results are reported in this paper). As far as the compressive strength is concerned, two strength classes have been addressed: the 40-60 MPa and 60-80 MPa range. The water to binder ratio was in the range of 0.33 ±0.2 for. Maximum size of coarse aggregate was limited to 20mm and 12 mm respectively. The workability was assured by a high-range water reducer admixture (VISCOCRETE 20HE), provided by SIKA Spain and the higher tensile strength by using steel fibres provided by Beckaert (DRAMIX RC-65/35-BN and DRAMIX ZP 305).

For selecting the admixture (VISCOCRETE 20HE, VISCOCRETE 5920, SIKAMENT TN100) mix stability and flowability was assessed on mortar tests, whose description is beyond the scope of this paper. The water-retention capability of the limestone filler was also verified. Mix proportions are indicated in Fig. 1. Quantities are expressed in relative volume and the aggregates have been considered in SSD conditions (Saturated and Surface Dry).

![Diagram](image)

Fig. 1 Proportions of trial mixes.
3 Concrete characterisation under standard conditions

3.1 Fresh-state characterization

All mixes were tested for their properties at the fresh state. Tests chosen were consistency as well as resistance to segregation using standard equipment (see Tab. 1). Fig. 2 left shows the aspect of the concretes (with up- and without down- fibres) at the end of the slump-flow test measured at time 0 h (no evidence of segregation neither water bled can be seen in the pictures) while results of all tests at different ages are those represented on Fig. 2 right.

Fig. 2 right shows that no fibres neither without fibres mixes can reach the 6h with exception of mix B0 (without fibres) and also the 4h with exception of both B mixes. Considering these results mix Bf must be tested at real scale accordingly (see also Tab. 1), when mix age reaches the 4 h.

![Image of concrete mixtures](image1)

![Image of slump-flow test](image2)

**Fig. 2** Fresh characterisation.

3.2 Influence of movable formwork machinery temperature

Striking time is usually shortened by accelerating concrete curing, commonly using a steam-curing cycle. It is known that the acceleration of strength gain leads to changes in concrete microstructure; porosity is coarsened and thus, final strength is reduced. Durability is also related to concrete porosity and thus, a special curing regimen at a temperature of 30° by using a climatic chamber has been done. Results of curing effect have been checked and compared with those ones of samples curing as standard prescribes. In all the cases results shown that the loss of strength have been less as specified.

3.3 Early age and hardened-state characterization

Mechanical performance was assessed by means of the setting time determination (by early age characterisation) and by means of the uniaxial compressive strength and tensile...
strength determination for ages up to 12 h [6]. Both set of results obtained from at least two samples, as well as the evolution of strength with time for all trial concretes are shown in Figures 3 and 4. Regarding setting time determination the following values (see Tab. 3 as follows) have been obtained. These low values have been obtained for the mixes A, C and D while for mix B the values have been a little higher (<5%).

Tab. 3 Setting time values.

<table>
<thead>
<tr>
<th>Curing Temperature (°C)</th>
<th>Initial setting time (h)</th>
<th>Final setting time (h)</th>
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<tbody>
<tr>
<td>20°</td>
<td>4.20</td>
<td>5.53</td>
</tr>
<tr>
<td>30°</td>
<td>2.73</td>
<td>3.72</td>
</tr>
</tbody>
</table>

Fig. 3 Compressive strength evolution up 28d.  
Fig. 4 Indirect tensile strength evolution up 28d

4 Conclusions

Although these conclusions should be taken as preliminary as real scale tests must be done, the results obtained up-to-date allow the following remarks to be made:

- Properly selected industrial materials are suitable to obtain tailor made mixes in the strength range 60-70 MPa that fulfil also the tensile strength requirements.
- Cement type might play an important role when thermal curing must be considered and a low loss at 28d strength is required. High early-age strength does not compromise long-term strength if a CEM I 52.5 is used.
- The use of properly aggregate grading and an efficient superplasticizer allowed the w/c ratio to be kept at a very low value without compromising mix flowability while obtaining higher strength at early ages.
- The need of using an accelerator is emphasized but the way to apply it must be study. If no a loss of workability can influence fresh and hardened concrete results.
- Its fitness to real requirements as well as the influence on durability is still under consideration.
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References


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