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# Plastometry for the Self-Compacting Concrete Mixes

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**Abstract.** Operative determination of consistence of self-compacting concrete mixes at plant or in construction conditions is an important problem in building practice. The Abram's cone, the Vebe's device, the U-box siphon, L-box or funnel tests are used in solving this problem. However, these field methods are targeted at determination of some indirect parameters of such very complicated paste-like material like concrete mix. They are not physical characteristics suitable for the rheological calculations of the coherence between the stress and strains, flow characteristics and the reaction of the concrete mix in different technological processes. A conical plastometer having higher precision and less sensitive to the inaccuracy of the tests in construction condition has been elaborated at the Concrete Mechanics Laboratory of RTU. In addition, a new method was elaborated for the calculation of plasticity limit  $\tau_0$  taking into account the buoyancy force of the liquid or non-liquid concrete mix. In the present investigation rheological test of the concrete mix by use the plastometer and the method mentioned earlier was conducted for different self-compacting and not self-compacting concrete mixes.

## 1. Introduction

Abram's cone outflow diameter measurement [1], Vebe's device, U-box siphon [2], L-box [3] or funnel tests are usually used to operatively determine rheological properties of self-compacting concrete at site [3].

In Abram's cone method, metallic cone is filled with the concrete mix, then by lifting the cone its content is poured on metallic sheet and outflow diameter is measured (see figure 1 a and b). The time when cone outflow reaches diameter 500 mm is also sometimes measured.

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The Vebe consistometer testing method is similar to simple Abram's cone test method for determination of the workability of concrete, but it has the advantage of a mechanized action. After lifting the slump cone, the concrete undergoes vibration to determine its slump (see figure 2).

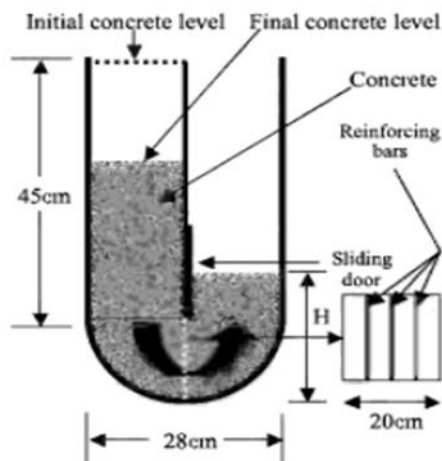
U-box siphon test method apparatus consists of a vessel that is divided by a middle wall into two sections. An opening with a moving gate is placed between the two compartments. Reinforcement bars are installed at the gate with centre-to-centre spacing of 50 mm. Bars create spacing of 35 mm. The left hand section is filled with concrete, then the gate is lifted. Concrete flows upwards into the other section. The height of the concrete in both sections is measured (see figure 3).



**Figure 1.** a) Abram's cone; b) Abram's cone outflow view (for its diameter measurement).

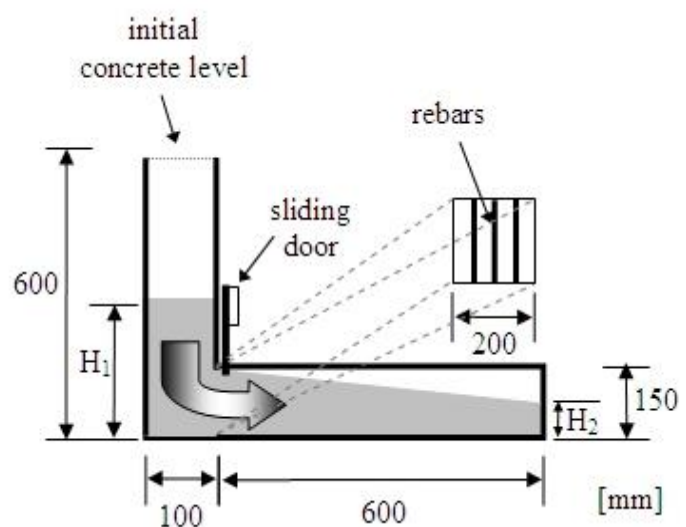


**Figure 2.** Vebe consistometer.



**Figure 3.** U -box siphon.

L – box test method apparatus consists of a rectangular L-shaped section box. The box consists of a vertical and horizontal section separated by a vertical gate. In front of the gate reinforcement bars are placed. The vertical section is filled with concrete, and then the gate is lifted. Concrete flows into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (see figure 4).



**Figure 4.** L-box.

V-funnel test method apparatus consists of V - shaped funnel and horizontal gate and the bottom of the funnel. The funnel is filled with concrete and horizontal gate is opened. The time that takes concrete to flow through the apparatus is measured (see figure 5). This method is extended sometimes by letting concrete rest in the funnel for 5 minutes and then test is performed. By this modification self-compacting concrete stability can be determined.



**Figure 5.** V-funnel test.

However, looking at such very complicated paste-like material like concrete mix, all these field methods can be used only for determination of some conditional characteristics. They are the slump of the conical sample or the outflow spot diameter in the Abram's cone method, degree of self-leveling in siphon, in the U-box method, it is time of flow-out in the funnel method or the Vebe time. Abram's cone method where spread diameter is measured can indicate yield stress level and measuring T500 (time when spread diameter reaches 500 mm) provides data on plastic viscosity. Similar to V- funnel and L-box apparatus, they indicate concrete's form filling ability and obstacle passing ability. Unfortunately, all these values are not physical characteristics suitable to determine rheological behavior of stress and strains of the liquid concrete mix, which is necessary for concrete flow characterization in different technological processes.

Rheological properties of concrete are described by Bingham visco-plastic model. Bingham flow is characterized by plastic limit or yield stress and viscosity coefficient  $\eta_{pl}$  as it is shown in equation 1:

$$\tau = \tau_0 + \eta_{pl}\dot{\gamma} \quad (1)$$

Where:  $\tau$  – shear stress;

$\tau_0$  – plastic limit or yield stress;

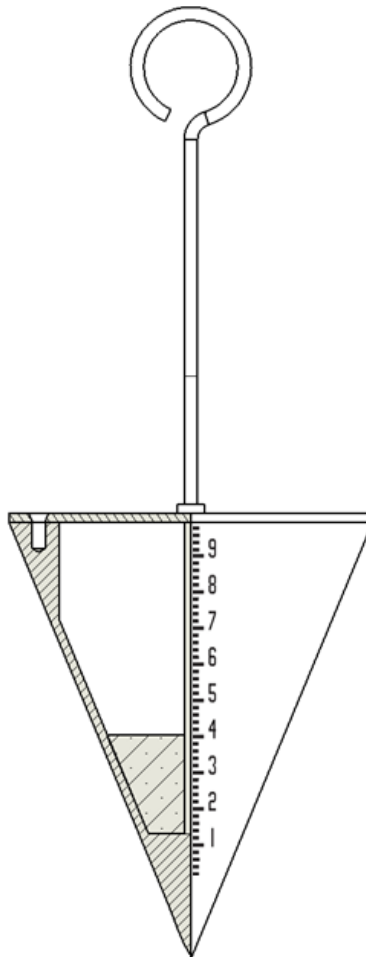
$\eta_{pl}$  –viscosity coefficient;

$\dot{\gamma}$  – shear rate.

## 2. Problem statement and the proposed solution

The main rheological parameter, which distinguishes conventional concrete mixes from self-compacting mixes, is the Bingham plasticity limit  $\tau_0$ . For the usual paste-like mixes, it is larger than zero, but for the liquid-like self-compacting concrete, it must be  $\tau_0 = 0$  in all situations.

In our investigation, a conical plastometer was used for plasticity limit  $\tau_0$  measurement of a cement mortar. Traditional view is that this device and method are suitable for small volume paste-like liquid samples with high  $\tau_0$  [4] values and are not suitable for determining  $\tau_0$  in big volume structures using liquid mixes having  $\tau_0 = 0$ .



**Figure 6.** Conical plastometer.



For the field tests, where concrete volumes are big and the used self-compacting mixes have a liquid-like rheological properties, the known method of determining the properties is not precise enough, because the conical indenter is too small (15 mm) and the buoyancy force of the liquid traditionally is also not taken into consideration.

Based on above-mentioned facts, in the Concrete Mechanics Laboratory of RTU a conical plastometer was elaborated, which has higher precision and is less sensitive to inaccuracy of the test (what is possible in field conditions). A new method was also elaborated for the calculation of plastic limit  $\tau_0$ , taking into account the buoyancy force of the liquid concrete:

$$\tau_0 = \frac{k}{h^2} (F_\Sigma - F_{Arh}) = \frac{k}{h^2} \left[ F_\Sigma - \frac{\pi h^3}{3} \cdot \rho_c \tan(\alpha) \right] \quad (2)$$

where  $F_\Sigma$  – the total axial force acting on the indenter;

$F_{Arh}$  – the buoyancy force;

$h$  – the immersion depth of the indenter into the concrete mix;

$k$  – the coefficient dependent on the angle  $\alpha$  of the pointed end of the indenter, if

$2\alpha = 45^\circ, k = 0.416$ ;

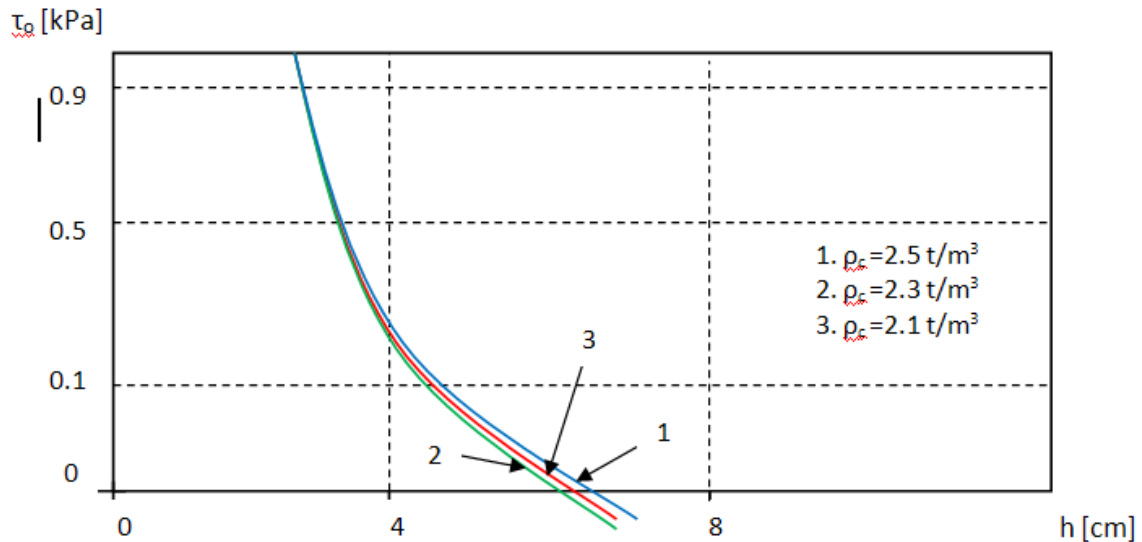
$\rho_c$  – the density of the concrete mix.

In figure 6 it is possible to see how the conical plastometer looks like, in figure 7 graphs calculated according to formula (2) for concrete mixes having different density are shown.

Conical plastometer was used for determining plasticity limit  $\tau_0$  of different self-compacting concrete mixes depending on time, counting it from mix preparation moment. All self-compacting concrete mixes were made with CEMEX CEM I 42,5 N cement. Measurement graphs are shown in figure 3. The actual duration of the test was 5 hours from the moment of adding water to the mix. In all cases, densities of concrete mixes were practically similar – for mix A it was  $2.32 \text{ t/m}^3$ , for mix B –  $2.30 \text{ t/m}^3$  and for mix C it was  $2.29 \text{ t/m}^3$ . Simultaneously Abram's cone tests were done for all mixes. Some differences for the three mixes were found in the standard Abram's cone outflow diameters – for mix A it was  $\varnothing 620 \text{ mm}$ , for mix B –  $\varnothing 670 \text{ mm}$ , for mix C –  $\varnothing 720 \text{ mm}$ .

Taking into account relatively small difference of the tested mix densities  $\rho$ , the starting depth of the conical plastometer was equal  $\sim 58 \text{ mm}$ , and value  $F_\Sigma = F_{Arh} = 48.2 \text{ kN}$  was obtained for the force. That means that all three tested mixes at the testing moment had plastic limit  $\tau_0 = 0$  and they can be characterized as viscous liquids.

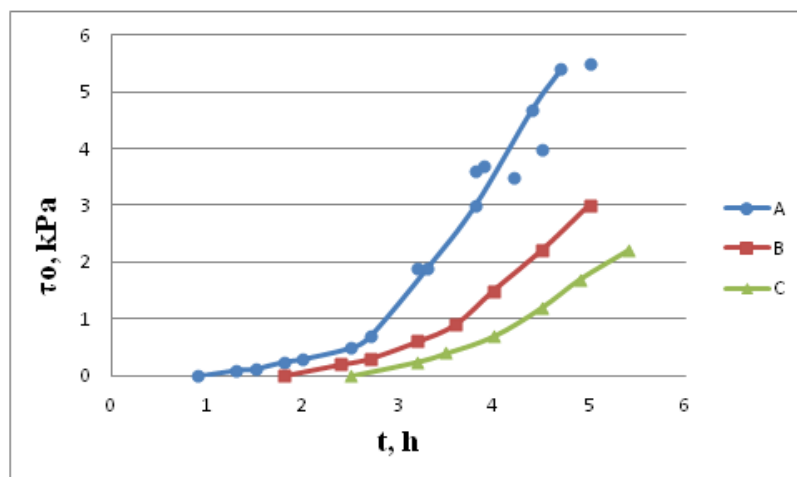
However, with time plastic limit values for all tested mixes changed from  $\tau_0 = 0$  and increased at different rate depending on particular mix composition. Kinetics of these processes is shown in figure 8. The early coagulation structure, which distinguishes the paste as a medium from the liquid in mix A starts to form approximately after 55 minutes from the mixing moment end. This short time is very important. It means that for reaching the maximal hardening potential of these real mixes, the construction technologist must have a short time to drive and to pour and compact this mix into the formwork.



**Figure 7.** The immersion depth of the plastometer  $h$  depending of the concrete mix plasticity  $\tau_0$ .  $\rho_c$  is the concrete mix density.

Every technological mechanical operation with the mix is done after the said term: transportation, pumping, pouring in the formwork and compacting of the mix will more or less destroy the early created and fresh coagulation structure of the cement mineral hydrates. In the later hardening time, the mentioned microdefects formed in the early phase will not overgrow and the hardened building structure will not obtain the potential strength.

As it is evident from figure 3, the critical term when  $F_\Sigma = F_{Arh}$  for the mix B is 1.75 h, but for the mix C it is 2.5 h.



**Figure 8.** Plasticity limit  $\tau_0$  growth kinetics for three different self-compacting concrete mixes A, B and C.



### 3. Conclusion

The proposed rheological test in site conditions is simpler and easier than the U-box siphon, L-box or funnel tests [1, 2, 3]. It is also easily repeatable and easy to use directly in the mixer or in the formwork.

In such a way, the use of the conical plastometer and the mentioned method account for the buoyancy force  $F_{Arh}$ , it is also possible to answer to the following questions:

- Is the tested mix self-compactable or not?
- If yes,  $\tau_0 = 0$ , but if not so ( $\tau_0 > 0$ ) we can calculate the real value of the mix plasticity limit (or the yield stress)  $\tau_0$  using the conical plastometer.
- Technologists can follow these measurements for further determination of the time of appearance and increase of plasticity limit  $\tau_0 > 0$  and for further kinetics investigation at early stage cement hydration product setting and formation forming new microstructure in the concrete.
- Taking into account term  $F_\Sigma$ , when  $F_\Sigma = F_{Arh}$ , while microstructure coagulation of the cement mineral hydrates has not yet started to occur, before starting further technological operations, we get a possibility to utilize all technological potential of the real mix for obtaining maximum strength characteristics as well as other qualities of the used self-compacting concrete.

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