

Comparative study of bleeding process in ordinary and self-compacting concrete – influence on the reliability of reinforced concrete elements

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ABSTRACT

Worldwide there is an intensive development of the construction sector, which is invariably associated with the building of various reinforced concrete elements and facilities. Increasingly attractive projects, significant support distances imply the use of large cross-sections of reinforced concrete, which are made with a high percentage of reinforcement. Their precise technological implementation and correct composition contribute to high durability and minimizing maintenance costs. This article examines the features of the bleeding process, which invariably accompanies all concrete works. Its influence on finished reinforced concrete elements is analyzed. A comparison of the bleeding process in ordinary concrete and self-compacting concrete is made, taking into account its influence on the bond strength between the two types of concrete and reinforcing steel. Conclusions are drawn and recommendations are given for the applicability of the two types of concrete, especially in elements with great thickness and/or height.

KEYWORDS

Self-compacting concrete, bleeding effect, bond strength concrete-reinforcement, durability

1. INTRODUCTION

In recent decades, large-scale construction projects combined with design standards have led to an increase in the amount of reinforcement used in new concrete structures. As a result are produced elements with a high percentage of reinforcement and small distances between the reinforcing bars.

A mandatory process during producing of new concrete elements is the compaction of the fresh concrete mix. For this purpose, needle vibrators, external formwork vibrators and other technological approaches are used, which aim is to penetrate the concrete everywhere into the formwork and to ensure its qualitative compaction. The compaction process becomes difficult by complex formwork shapes and large amounts of reinforcement. Improper or insufficient compaction of the fresh concrete mix can lead to visible surface defects, but also to reduced bond strength between concrete and reinforcing steel inside the element.

While visible defects can be treated and reduced, deep defects appear at a later stage, when the facility is already in use, and often cannot be repaired. Additional costly processes are required to strengthen the existing structure, and if this is impossible, the construction service life is reduced significantly.

For this reason, for elements with a high percentage of reinforcement, are recommended and applied specific highly workable concretes, which kind of concrete can fill the formwork without the need for vibration. An example of such a type of construction material is self-compacting concrete (SCC).

A research team including K. Maekawa, K. Ozawa, M. Ouchi and H. Okamura [1, 2] developed a solution to the problem of poorly compacted reinforced concrete elements by proposing the use of self-compacting concrete. Its use in the construction sector was reported for the first time in Japan in the construction of the abutments of the Akashi-Kaikyo Bridge, built in April 1998.

The wider use of SCC can lead to shorter construction times and to reduce the need for skilled workers for concrete placement [5].

The purpose of this article is to summarize the influence of bleeding effect in conventional concrete and SCC, providing recommendations for their applicability in modern reinforced concrete structures.

2. FEATURES OF SELF-COMPACTING CONCRETE

2.1. Paper Length, Size and Orientation

SCC is a highly plastic mixture that does not segregate during placement and can fill formwork without the need for additional external intervention, i.e. there is no vibration. It has been found that the use of this type of concrete reduces noise and working hours [8]. The fresh mix of SCC is more resistant to segregation [5] and is suitable for use in places with narrow openings where placing conventional concrete and its vibration are difficult.

The characteristics of SCC lead to a shorter construction schedule and to produce concrete structure with better quality, which are more homogeneous [5]. Using this type of concrete, the occurrence of deficiencies and defects in the element due to bleeding or segregation, which are caused by improper vibration activity, can be avoided.

The applicability of SCC occurs after a properly determined design mix that guarantees the "flowability" of the concrete and prevents segregation.

When determining the mix proportion for SCC, certain features must be taken into account, which are given in the EF-NARC prescriptions [3,4], as follows:

- Total powder content - $(380 \div 600) \text{ kg/m}^3$ includes the amount of cement and fine mineral admixture;
- Mandatory use of fine mineral admixture – in the ratio of water to total powder content by volume within the limits $W/P = (0.85 \div 1.1)$. Fine additives are considered particles with a size $\leq 0.125 \text{ mm}$;
- Coarse aggregate with a limited size of up to 20 mm and according to some authors up to 16 mm maximum size – quantity $(750 \div 1000) \text{ kg/m}^3$;
- Water - $(150 \div 210) \text{ dm}^3/\text{m}^3$, its quantity being strictly monitored throughout the entire process of preparing the SCC mixture;
- Mandatory use of superplasticizers (SP) – chemical additives that improve the workability of SCC.

The fresh mix of SCC is required to be subjected to some more specific tests to confirm its ability to pass through obstacles, to be resistant to segregation, etc. Some of these tests are specific only to this type of concrete and have their normative characteristics according to BDS EN – spreading test, L-box test, etc. [6, 7].

3. BLEEDING AND ITS INFLUENCE ON THE BOND STRENGTH BETWEEN CONCRETE AND REINFORCEMENT

3.1. Nature of Bleeding

After the fresh concrete mix is placed in the formwork and vibrated, there is a period of time in which it is not yet hardened. During this period, the heavy particles of the concrete mix – coarse aggregate and sand, begin to settle in depth. This leads to the expulsion of free water (not included in chemical compounds) to the upper layers of the placed fresh concrete.

Total bleeding is divided into two components [10] – internal and external. External bleeding is the amount of water that reaches the surface of the concrete and this water is visible.

Part of the free water, when moving upwards, encounters obstacles – coarse aggregate grains or reinforcing bars, and the water is retained under them. This is described like internal bleeding. This process is invisible to the naked eye, but is an inevitable part of the concrete placing process. A large part of the water by internal bleeding is retained around the coarse aggregate grains and/or reinforcing bars [10]. Over time, the water evaporates, leaving voids in the interior of the finished reinforced concrete element. This leads to permanent porosity inside the material, and due to the created cavities, there is no connection between concrete and reinforcing steel, as well as between cement stone and coarse aggregates. This, according to some authors [9], leads to a decrease in the strength between the concrete components and to a general decrease in the bond strength between concrete and reinforcing steel.

The combination of bleeding, settling of heavy components in the fresh concrete mix, and segregation, according to some authors [11], are the main cause for the formation of voids under the horizontal reinforcement in reinforced concrete elements. In the absence of vibration, as in the case of SCC, some of the processes that cause or increase bleeding are missing.

The methods to determining the total bleeding are divided into two directions – direct measurement of the surface water discharged - external bleeding and a methodology for determining the internal bleeding. The above-mentioned team of authors [10] suggests that the measurement of internal bleeding should be done using a non-contact laser sensor, due to

the impossibility of direct visual inspection. The value of internal bleeding [10] can be defined as the difference between an empirically determined total bleeding and the measured external bleeding.

3.2. Top Bar Effect

The process of settling of heavy components in the fresh concrete mix and bleeding have an adverse effect on the upper horizontal reinforcing bars. As a result of these processes, voids are formed under the reinforcing bars, especially under those bars, which are located at a height of more than 30 cm from the bottom of the formwork. In scientific literature, this phenomenon is known as the "top bar effect". The formed voids reduce the bond strength between concrete and reinforcement, which leads to an overall decrease in the load-bearing capacity of the element. An additional undesirable effect is when the already formed cavities are filled with a solution from an aggressive environment, which causes corrosion in the concrete-reinforcement contact area. After conducting researches, it was found that in ordinary concrete, bleeding process and the top bar effect are significant.

The influencing factors are mostly dependent on the composition of the concrete, the bar position and the shape of the reinforcing bars. To minimize the influence of the "top bar effect", mainly caused by bleeding, Eurocode 2 introduces a coefficient that increases the overlapping and anchoring length of the reinforcing bars for elements with a height greater than 30 cm. The length is increased by about 30%.

3.3. Factors That Influence the Bleeding Process

Previous studies [13] have shown that the main factor influencing bleeding process and hence the bond strength between concrete and reinforcement, is the water-cement ratio. At a W/C ratio of 0.65, the difference in the bond strength between SCC and ordinary concrete reaches 30%. When reducing W/C=0.45, the difference drops to 10% between the two types of concrete. At both W/C ratios studied above, SCC is less affected by bleeding, which can be explained by the increased amount of fine mineral admixture in its composition. This admixture accumulates water and prevents or minimizes the bleeding process.

The above-mentioned authors [10] also confirmed that a higher W/C ratio leads to a significant increase in internal bleeding. Their exams are provided only with ordinary concrete compositions. Fig. 1 shows the degree of bleeding /external and internal/, expressed in percentages for different W/C ratios. Composition 2 has W/C=0.469, composition 3 – W/C=0.469 and composition 5 – W/C=0.550.

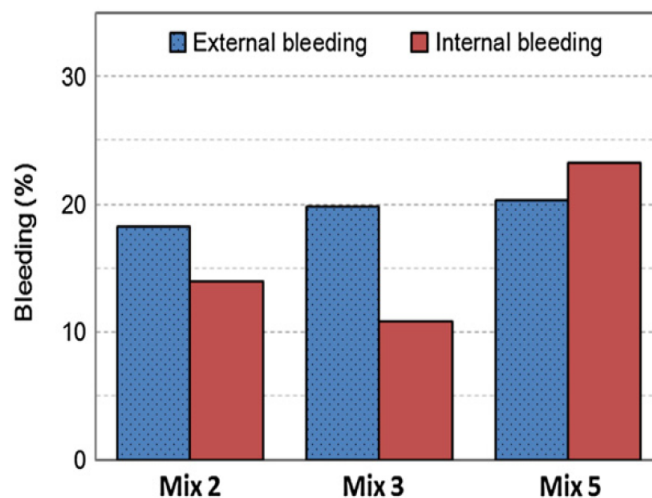


Figure 1: External and internal bleeding, reported in % for ordinary concrete compositions with different W/C ratios and different coarse aggregates grain shapes [10]

The shape of the coarse aggregates also has a significant influence on the internal bleeding. Concrete mix 2 and 3 have the same W/C ratio, but in composition 3 the coarse aggregates grains have a regular spherical shape. As can be seen from Fig. 1, composition 3 has lower internal bleeding values compared to all other tested compositions of ordinary concrete.

3.4. Bond Strength Between Concrete and Reinforcement by Bleeding

Studies have been conducted and they show that the decrease in bond strength between concrete and reinforcement along the height of the element can vary from 30% to 55%. The loss in bond strength is being greater in ordinary concrete, which is vibrated after being placed in the formwork.

The effect of bleeding on the bond strength was investigated for different diameters of reinforcing steel [8]. For some of the most commonly used cross-sections, namely Ø 10, Ø 12 and Ø 16 mm, the dependence has been confirmed that with increasing height from the bottom of the formwork, the bond strength decreases - the reason is cavities resulting from

bleeding. For reinforcement diameter of $\varnothing 16$ mm, the drop in the bond strength reaches, according to some authors [8], up to 106%, and for a diameter of $\varnothing 12$ mm – up to 63% in ordinary concrete. These values are 20% and 9% respectively for the same diameters, but for SCC. As expected, the loss in the bond strength is the smallest for the smallest diameter. This pattern can be explained by the fact that a larger diameter represents a greater obstacle that free water may encounter as it moves toward the surface.

To study the change in the bond strength caused by bleeding, some authors [8, 12] created formwork forms for a column, with reinforcing bars with the same diameter anchored along the height. In the formwork are created the so-called lower, middle and upper zones, in which the change in the bond strength is studied – Fig. 2. In both experimental setups, the exact contact length between concrete and reinforcing steel was ensured using plastic tubes that were placed on the reinforcing bar. Additionally, the holes are filled to prevent mortar to entering in the hole between the reinforcement and the plastic pipe. A tensile force is applied to the free end of the reinforcement emerging from the formwork to determine the bond strength.

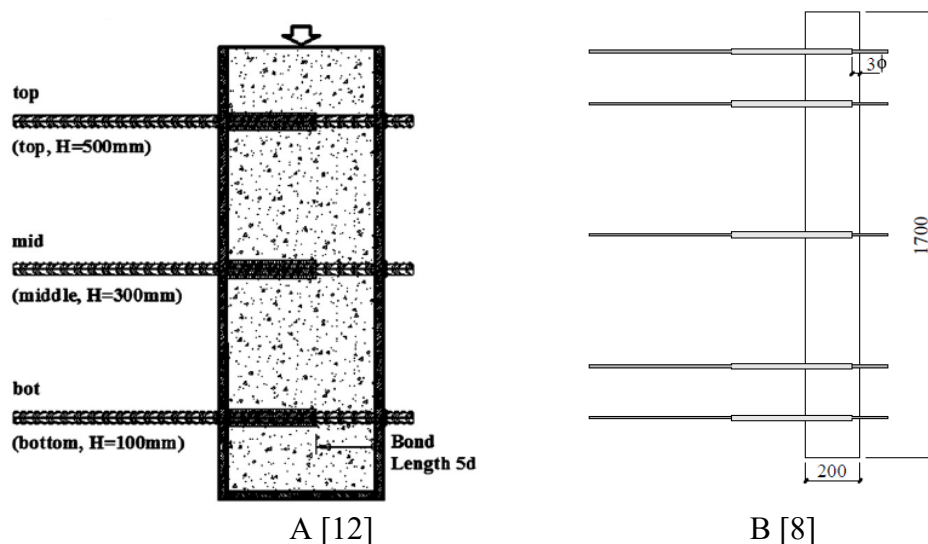


Figure 2: Experimental setup A [12] and B [8] for determining the variation in bond strength in height affected by bleeding

After conducting the pullout test, all literature sources reviewed in this article observe a similar pattern – with increasing the height, ordinary concrete compositions are more strongly influenced by bleeding. Accordingly, the decrease in bond strength is greater by ordinary concrete. In Fig. 3, the authors [12] observed that the ratio of the bond strength for upper/lower reinforcing bars at different W/C ratios in the SCC compositions is close to unity /1/. In SCC mixes with increasing W/C ratio, this ratio /upper-lower reinforcement/ remains around unity /1/, which proves that decrease in bond strength along the height of the column is insignificant. For the SCC compositions, the ratio of the bond strength between the upper and lower reinforcement does not fall below 0.7 at all used W/C ratios. In ordinary concrete, even at the lowest W/C ratio, the bond strength between the upper and lower reinforcement reaches 0.7 once – see Fig.3.

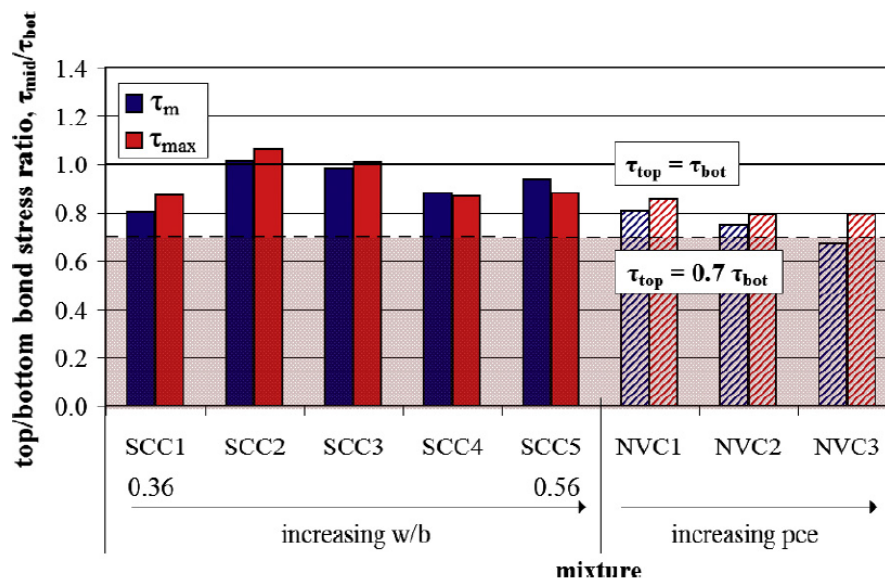


Figure 3: Relationship between the bond strength of top and bottom reinforcement for SCC and normal vibrated concrete (NVC) [12]. “PCE” in figure means superplasticizer

3.5. Corrosion of Concrete and Reinforcing Steel Due to Bleeding

Bleeding, as mentioned above, leads to the so-called “top bar effect”. It contributes to create voids under the reinforcing steel at a height of its placement more than 30 cm above the bottom of the formwork [11]. Studies have shown that such bars corrode much faster in the presence of aggressive environments than others located lower in the formwork. The presence of voids caused by bleeding can initiate corrosion in reinforcing bars at significantly lower levels of aggressive agents. In bars affected by the “top bar effect” is observed significant corrosion situated on the underside of the bar, while their top surface remains intact - Fig. 4.

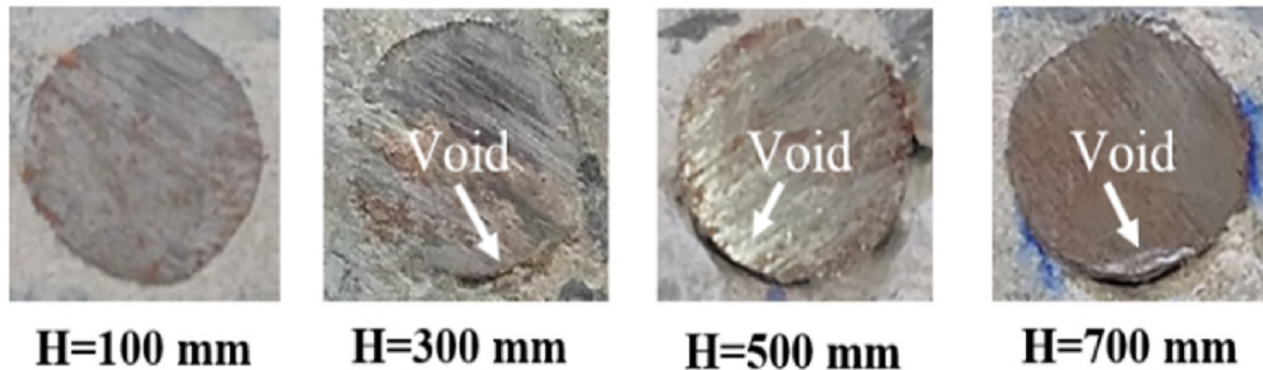


Figure 4: Cross-section of bars located at different heights of 100 mm, 300 mm, 500 mm and 700 mm from the bottom of the formwork [11]

4. CONCLUSIONS

As a result of the literature review and comparative analysis of bleeding process in conventional and self-compacting concrete, the following conclusions can be made:

- The ratio of water to total powder content W/P affects bleeding, as when the W/P ratio decreases, the free water, which is the basis of bleeding, decreases. As a result of the above, the total bleeding in the fresh concrete mix decreases;
- The bleeding strongly influences the formation of voids in the concrete structure. This defect is noticeably observed in bars that are located more than 30 cm above the bottom of the formwork. As the height at which the longitudinal reinforcement is placed increases, the amount of voids under it, caused by bleeding, increases;
- Due to bleeding and the so-called “top bar effect”, as the diameter of the reinforcing steel increases, the bond strength between reinforcement and the concrete decreases in height. This is more noticeable in conventional concrete, while in SCC the influence of the diameter is less pronounced;
- The reinforcing steel, which is located higher in the reinforced concrete element, is subject to a stronger influence of aggressive agents from the environment, due to the presence of more voids around it and connected cavities through which the aggressive environment can enter the interior;
- As the height of the reinforcement increases in both types of concrete, a decrease in the bond strength is observed. This effect is more noticeable in ordinary concrete;
- The need to increase the length of overlapping and anchoring of the reinforcement by 30% is confirmed. This is necessary if the reinforcement is placed at a height of more than 30 cm from the bottom of the formwork. This percentage increase is completely suitable for ordinary concrete compositions, and it can be further increased if the expected height of the concreted element and the diameter of the reinforcement used are more than 20mm;
- To minimize the effects of bleeding, it is recommended that for tall elements or those with a thickness of over 30 cm, bars with a smaller diameter be used for upper reinforcement, if the structural requirements allow.

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