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Use of the Equivalent Mortar Phase to Assess Thixotropy of Fresh SCC – Prediction of Interfacial Bond Strength between Successive Placement Lifts

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Abstract:
Self-consolidating concrete (SCC) is very sensitive to delays or stoppages between successive lifts during casting, especially given that vibration is prohibited with this highly flowable type of concrete. The investigation reported in this paper seeks to quantify the effect of mixture proportioning on thixotropy along with the resulting effect on interfacial bond strength of hardened material that could result from successive lifts. The suitability of the equivalent mortar phase to simplify testing protocols and appropriately predict SCC properties was given particular attention; the concrete-equivalent-mortar (CEM) mixtures are derived from SCC by eliminating the coarse aggregate fraction and replacing it by an equivalent quantity of sand having equal surface area. Tests results have shown that SCC and CEM mixtures prepared with combinations of increased cement content, silica fume, and/or viscosity-modifier led to higher levels of thixotropy. Yet, the responses determined using SCC were higher by around 1.6 times than those of CEM, given the differences in unit weight and air content between both materials. Good correlations are established between thixotropy and interfacial bond strengths of SCC and CEM mixtures.

Key words:
Self-consolidating concrete, concrete-equivalent-mortar, thixotropy, bond strength, yield stress, stability

1 INTRODUCTION

Highly flowable self-consolidating concrete (SCC) typically exhibits thixotropic behavior characterized by reduced apparent viscosity during motion, yet with relatively fast recovery when left at rest. The reduced viscosity is necessary during concrete agitation to facilitate placement by gravity with improved filling ability [1, 2]. As soon as placement is completed, the reversible phenomenon of thixotropy associated with build-up of cementitious structure takes place over time. Earlier studies showed that lack of structural recovery can lead to reduced material stability including bleeding and segregation that can weaken the quality of interface between aggregate and cement paste with direct effects on permeability, bond to steel, and mechanical properties [3, 4]. Also, fast restructuring could be particularly beneficial to reduce the lateral stresses developed on vertical formworks [5]. In contrast, however, high thixotropic SCC exhibiting fast recovery could not be appropriate during successive casting lifts, as this would create cold joints and weak interfaces in the hardened structure. Some researchers reported mechanical and bond losses reaching 60 % due to weak SCC interfaces together with increased vulnerability towards porosity and permeability along the interface [6].

In literature, thixotropy is typically evaluated under motion [1, 5], i.e. by subjecting the material to given shearing regime and recording the structural breakdown curves over time. However, when placement is completed, several authors focused their studies on the recovery aspect of thixotropy, as this could be more practically relevant in terms of SCC performance and strength development after casting. For example, Billberg [7] measured the increase of SCC yield stress τ_o at rest by slowly rotating the concrete rheometer in order to distinguish the reversible flocculation due to thixotropy from the irreversible evolution due to normal slump loss. Using this methodology, the author showed that τ_o increases linearly with resting time. Roussel [8] proposed a model that predicts the variations of τ_o developed over time as a function of thixotropy as $\tau_o(t_{rest}) = \tau_o(t_o) + A_{Thix} t_{rest}$, where t_{rest} is the resting time and A_{Thix} structuration rate determined as the

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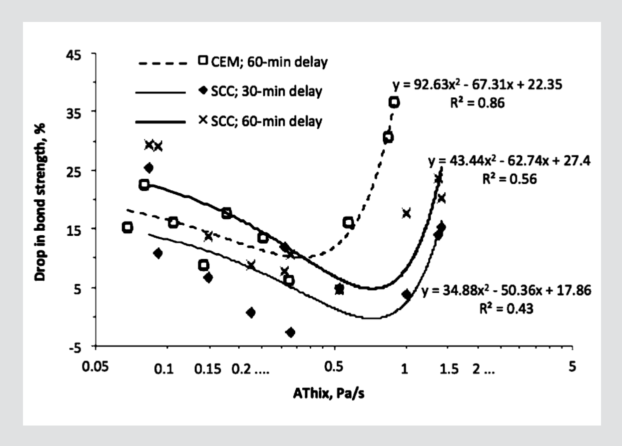

Figure 12: Relationships between A_{Thix} and drop in bond strength for SCC and CEM mixtures.

4 SUMMARY AND CONCLUSIONS

This research project is undertaken to evaluate the practical consequences of thixotropy on the drop in interfacial bond strength resulting from successive SCC placement lifts. The suitability of the CEM approach to simplify testing protocols and appropriately predict SCC performance was investigated; the CEM possesses the same concrete composition, except that the coarse aggregate fraction greater than 4.75 mm is replaced by an equivalent quantity of sand having equal surface area. Good correlations were established between HRWR demand, air content, unit weight, and bleeding of SCC and CEM. Mixtures prepared with combinations of increased cement content, silica fume, or VMA led to higher A_{Thix} magnitude; nevertheless, the responses determined using CEM were lower by around 1.6 times than those of SCC. Knowing the static nature of tests realized, the decrease in CEM thixotropy was related to reduced unit weight and higher air content than corresponding SCC. The coarse aggregate fraction is expected to play a secondary role, as it mainly influences the internal friction and collision during dynamic conditions. A set-up inspired from ASTM C1042 Test Method was developed to evaluate the effect of delays between successive casting lifts on interfacial bond strength of hardened material. Regardless of SCC or CEM, mixtures filled without interruption exhibited increased bond compared to similar mixtures cast in two layers implying, in other words, that multi-layers casting creates weak interfaces in the hardened material. The highest bond strength drop occurred for highly stable with A_{Thix} higher than 0.75 Pa/s and unstable mixtures with A_{Thix} less than 0.2 Pa/s. In the former case, the drop in bond was related to the extremely low bleed water that creates dry-skin layer on top surface of the first cast, and consequently leads to reduced adhesion with the second layer. In contrast, the decrease in bond for unstable mixtures was related to excessively increased bleed water, thus reducing homogeneity of specimen together with increased w/c that weakens the diagonal section.

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REFERENCES

[1] Boisly M, Kastner M, Brummund J, Ulbricht V: General aspects of yield stress fluids – Terminology and definition of viscosity, Appl. Rheol. 24 (2014) 14578.
[2] Phan TH, Chaouche M: Rheology and stability of self-compacting concrete cement pastes, Appl. Rheol. 15 (2005) 336 – 343.
[3] Zhu, W, Gibbs, JC, Bartos PJM: Uniformity of in-situ-properties of self-compacting concrete in full-scale structural elements, Cem. Con. Comp. 23 (2001) 57 – 64.
[4] Assaad JJ, Khayat KH, Daczko J: Evaluation of static stability of self-consolidating concrete, ACI Mater. J. 101 (2004) 168 – 176.
[5] Assaad JJ, Khayat KH: Effect of viscosity-enhancing admixtures on formwork pressure and thixotropy of self-consolidating concrete, ACI Mater. J. 103 (2006) 280 – 287.
[6] Roussel N, Cussigh F: Distinct-layer casting of SCC: The mechanical consequences of thixotropy, Cem. Con. Res. 38 (2008) 624 – 632.
[7] Billberg P: Form pressure generated by self-compacting concrete – Influence of thixotropy and structural behaviour at rest, Ph.D. thesis, The Royal Institute of Technology, Stockholm (2006).
[8] Roussel N: Rheology of fresh concrete: from measurements to predictions of casting processes, Mater. Struct. 40 (2007) 1001 – 1012.
[9] Geiker MR, Brandl M, Thrane LN, Nielsen LF: On the effect of coarse aggregate fraction and shape on the rheological properties of self-compacting concrete, Cem. Con. Agg. 24 (2002) 3 – 6.
[10] Murata J, Kikukawa H: Viscosity equation for fresh concrete, ACI Mater. J. 89 (1992) 230 – 237.
[11] Noor MA, Uomoto T: Rheology of high flowing mortar and concrete, Mater. Struct. 37 (2004) 513 – 521.
[12] Ferraris C, de Larrard F: Testing and modelling of fresh concrete rheology, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, NISTIR 6094 (1998) 61.
[13] Yahia A, Tanimura M, Shimabukuro A, Shimoyama Y: Effect of rheological parameters on self-compactability of concrete containing various mineral admixtures, Proceedings of the 1st international RILEM symposium on self-compacting concrete, A Skarendhal and O Petersson (Eds.), Stockholm (1999) 523 – 535.
[14] Schwartzentruber A, Catherine C: Method of the concrete equivalent mortar (CEM) - A new tool to design concrete containing admixture, (in French), Mater. Struct. 33 (2000) 475 – 482.
[15] Assaad JJ, Khayat KH: Assessment of thixotropy of self-

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consolidating concrete and concrete-equivalent-mortar – Effect of binder composition and content, ACI Mater. J. 101 (2004) 400 – 408.
[16] Assaad JJ, Harb J, Chakar E: Relationships between key ASTM test methods determined on concrete and concrete-equivalent-mortar mixtures, ASTM Internat. J. 6 (2009) 14.
[17] Assaad JJ, Harb J: Surface settlement of cementitious-based materials determined by oedometer testing, Mater. Struct. 44 (2011) 845 – 855.
[18] Assaad JJ, Daou Y, Harb J: Use of CEM approach to develop and optimize high-performance underwater concrete, J. Mater. Civil Eng. 23 (2011) 1094 – 1102.
[19] Assaad JJ, Harb J, Khayat KH: Use of triaxial compression test on mortars to evaluate formwork pressure of SCC, ACI Mater. J. 106 (2009) 439 – 447.
[20] ASTM C1042-99: Standard test method for bond strength of latex systems used with concrete by slant shear, ASTM International, West Conshohocken (1999).
[21] ASTM C1437-07: Standard test method for flow of hydraulic cement mortar, ASTM International, West Conshohocken (2007).
[22] ASTM C143/C143M-05: Standard test method for slump of hydraulic cement concrete, ASTM International, West Conshohocken (2005).
[23] ASTM C231/C231M: Standard test method for air content of freshly mixed concrete by the pressure method. ASTM International, West Conshohocken (2014).
[24] ASTM C138/C138M: Standard test method for density (unit weight), yield, and air content of concrete. ASTM International, West Conshohocken (2014).
[25] ASTM C232: Standard test method for bleeding of concrete, ASTM International, West Conshohocken (2014).
[26] Nguyen QD, Boger DV: Direct yield stress measurement with the vane method, J. Rheol. 29 (1985) 335 – 347.
[27] Assaad JJ, Harb J, Maalouf Y: Measurement of yield stress of cement pastes using the direct shear test, J. Non-Newtonian Fluid Mech. 214 (2014) 18 – 27.
[28] Lu G, Wang K: Investigation into yield behavior of fresh cement paste: model and experiment, ACI Mater. J. 107 (2010) 12 – 19.

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