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Chloride Thresholds and Limits for New Construction

SP-308

Editors:
David Tepke, David Trejo, and O. Burkan Isgor

American Concrete Institute
Always advancing

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Preface

The detrimental influence of chlorides on the corrosion of reinforcing steel in concrete has been widely documented. The literature clearly shows that chloride concentration at the steel level must exceed a critical chloride threshold to initiate active corrosion of reinforcement embedded in concrete. It is now well accepted that this critical chloride threshold is not a unique value, but rather a range that depends on several factors. Regardless, placing concrete with chloride concentrations above the critical chloride threshold for a particular situation would result in active corrosion of the reinforcement and is therefore undesirable. Unnecessarily restrictive limits, however, can lead to preclusion of some otherwise acceptable materials or require use of supplemental materials or alternative mixture designs that may increase costs or impact sustainability. Thus, there is a need from a practical standpoint to establish conservative, yet reasonable, limits so that the effects of corrosion can be managed without undue restrictions. ACI documents place limits on the amount of chlorides that can be incorporated into new concrete – these limits are referred to as the allowable admixed chloride limits.

Documents published by ACI Committees 201 and 222 currently recommend limiting admixed chlorides based on a mass percentage of the portland cement in the concrete mixture. Other documents, such as ACI 318, limit the admixed chlorides based on weight percentage of cement. With the movement of the industry towards greener systems, the inclusion of supplementary cementitious materials (SCMs) as part of the cement could be beneficial. SCMs, however, when used in large quantities, have been reported to decrease the pH of the pore solution, which may lower the critical chloride threshold values. If the critical chloride threshold values for concrete systems containing only portland cement are different than the critical chloride threshold values for systems containing portland cement and SCMs, the published allowable admixed chloride limits may not be applicable. A further complication in establishing values exists due to performance-based cements in which the specific amounts of SCMs might not be known to the specifier.

This special publication (SP), based on two technical sessions held during the Fall 2015 Concrete Convention and Exposition in Denver, CO, November 8-11, 2015, addresses challenges associated with allowable admixed chloride limits, critical chloride thresholds, testing for the critical chloride threshold, binding of chlorides in different systems, and how admixed chlorides influence service life. Authors and presenters from North America and Europe provided a variety of perspectives, experiences, and opinions. Based on the presentations, the open discussion that followed the presentations, and the papers in this SP, evidence indicates that allowable chloride limits should be based on cementitious materials content including both portland cement and SCMs. However, because research on the amount of chlorides required to initiate corrosion in systems containing high SCM replacement levels suggests that there may be upper limits at which the inclusion is appropriate, it was suggested that it may be appropriate to place limits on the replacement percentages of SCMs used for calculations of cement content when determining allowable admixed chloride limits. Although the Denver sessions and the papers in this SP provide a significant move forward on better defining allowable chloride limits and likely allow for refinement of current recommendations in ACI documents, more research is needed.

On behalf of ACI Committees 201 and 222, the editors sincerely thank all authors and presenters for their efforts and contributions to the presentations, open forum, and this SP volume. Special thanks are extended to the peer reviewers of the manuscripts for their constructive comments and recommendations. The editors are also indebted to the ACI staff for their assistance in organizing the sessions, organizing the open forum, and in preparing this volume. The editors earnestly hope that this symposium and SP volume will serve as a valuable resource to those searching for data, guidance, and better clarity on allowable admixed chloride limits in concrete.

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CHLORIDE THRESHOLD VALUES IN CONCRETE – A LOOK BACK AND AHEAD

Ueli M. Angst and Bernhard Elsener

Synopsis: Over the last 60 years, extensive research efforts aimed at determining the so-called chloride threshold value in reinforced concrete. The belief that such a threshold exists is the root of all efforts to measure and model chloride ingress into concrete. This paper addresses the usefulness of this established concept by evaluating the experience available for portland cement systems. Additionally, it is critically discussed whether the concept can be applied to modern materials, particularly SCMs. Finally, suggestions for future research are made.

It is concluded that the pronounced stochastic nature of the chloride threshold currently permits only corrosion prognoses with large uncertainties. It is shown that even the most sophisticated chloride transport model in concrete will not significantly improve this. Instead of refining mass transport models, future research should thus aim at finally understanding the relevant parameters governing corrosion initiation in concrete. There is strong indication that a number of such parameters are overlooked in the current concept of the chloride threshold value. We believe that as long as initiation of chloride-induced corrosion is not fully understood, it does not make sense to continue applying the (unsuccessful) concept of the chloride threshold value to modern materials.

Keywords: Chloride threshold value; Chloride induced corrosion; Critical chloride content; Durability, Reinforcement corrosion; Service life modelling; Supplementary cementitious materials; Sustainabilit

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INTRODUCTION

In many countries around the world, portland cement has for decades been the most used type of cement to build reinforced concrete infrastructure. In recent years, however, portland cement has increasingly been substituted with supplementary cementitious materials (SCMs). Table 1 illustrates this by means of the example of Switzerland. While for some of these materials there may be positive track records from certain countries – for instance for ground granulated blast furnace slag that has been used in the Netherlands for roughly a century – the diversity of cementitious materials and mineral binders to be used in the future is expected to increase, owing to, amongst others, reasons of local availability of raw materials (Angst et al. 2012). The main motivation for reducing the "clinker factor", i.e. to increasingly substitute portland cement clinker partially with SCMs, is on the one hand to reduce the environmental impact, particularly by reducing the carbon footprint, and on the other hand to improve the durability. Achieving sustainability clearly not only requires decreasing the environmental footprint of the materials at the time of their production, but to combine this with long and maintenance free service lives of the structures in their actual exposure environments.

Due to the lack of long-term experience on the field performance of modern materials, we are forced to make predictions. This is done based on theoretical reasoning and on accelerated laboratory (or field) testing, believed to provide a basis to extrapolate the short-term behaviour to long-term and field conditions.

Essentially, these efforts consist in adapting concepts established with experience from portland cement and applying them to the new materials. The conceptual understanding of degradation due to chloride-induced corrosion of reinforcing steel in concrete evolved in the second half of the last century and has since then essentially been unchanged. The widespread hypothesis is that the chloride concentration at the surface of the embedded steel is the by far most important parameter, and hence that initiation of corrosion can be predicted by reducing the entire problem to a question of chloride concentrations only. This is illustrated by the extensive research efforts performed over the last 60 years, seeking to determine the so-called *chloride threshold value* or *critical chloride content* (Angst et al. 2009), i.e. to specify a threshold concentration below which, conceptually, there is no corrosion and above which corrosion occurs.

The belief that such a threshold exists is also the root of all research efforts to measure and model chloride ingress into concrete. This issue received considerable research attention over the last decades, and a high number of test methods have been devised internationally for assessing the ability of concrete to resist chloride penetration, as e.g. reviewed in Tang et al. (2012).

Table 1 — Types of cement sold in Switzerland in the years 1996, 2006, and 2015, illustrating the sharp transition from Portland cement to blended cements; data from (CemSuisse).

Cement type	Designation (acc. to EN 197-1)	1996	2006	2015
Portland cement	CEM I	87%	37%	13%
Blended Portland cement	CEM II	11%	60%	83%
Slag cement	CEM III	<1%	<2%	<1%
Other		<2%	<2%	<4%