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Influence of reinforcement spacers on mass transport properties and durability of concrete structures

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ABSTRACT

Spacers are ubiquitous in reinforced concrete, but their influence on durability is unclear. This paper presents the first study on the effects of spacers on mass transport and microstructure of concrete. Samples with different spacers, cover depths, aggregate sizes, curing ages and conditioning were subjected to diffusion, permeation, absorption and chloride penetration, and to μXRF, BSE microscopy and image analysis. Results show that spacers increase transport in all cases, the magnitude depending on spacer type and transport mechanism. Plastic spacers produced the largest increase, followed by cementitious spacers and then steel chairs. The negative effect is due to a porous spacer-concrete interface that spans the cover where preferential transport occurs. Spacers may seem low value, small and inconsequential, but because they are placed every ≤1 m along rebars, their overall effect on ingress of external media is significant. This is not currently recognised by standards or by most practitioners.

1. Introduction

Spacers are essential components in reinforced concrete structures. Their function is to secure steel reinforcements in the correct position within the formwork to prevent movement prior to and during concreting so that the required cover is obtained in the finished structure. The size of spacer determines the size of the cover depth to reinforcement, which in structural design, is defined according to the severity of exposure environment, required durability and fire resistance. Achieving adequate depth and quality of concrete cover is critical because it protects embedded steel reinforcement from the external environment. It is well-known that inadequate cover is the major factor causing premature corrosion of reinforcement, the principal form of degradation of concrete structures. In structural design, it is assumed that achieving the specified cover ensures that the as-built structure achieves the expected design performance in terms of durability, fire resistance and serviceability (crack width).

Spacers are made of plastic, metal or cementitious materials, and are available in various sizes and shapes (see Fig. 1). In this paper, we will use a generic term "spacers", but recognising that other terms may be prevalent elsewhere, e.g. bar supports, wire chairs, bolsters, continuous runners, and dowels. Although many types of spacers are available commercially, they generally fall into one of six categories: a) plastic spacers with integral clip-on action for horizontal rebars of 20 mm or less, b) plastic end spacers that fit ends of rebar for end cover, c) plastic wheel/circular spacers for vertical rebars in columns and walls, d) cementitious block spacers for bar size >20 mm in heavily-reinforced sections; e) continuous line spacers that are either cementitious or plastic, of constant cross-section in typically 1 m lengths to support several bars; and f) steel wire chairs that may be single, continuous or circular, to support the top horizontal rebar from lower rebar or to separate layers of vertical rebars. Of all the available types, plastic spacers are the most popular because they are cost effective and they do not need to be wire tied to rebar, which is labour intensive. For further details on spacer types, readers can refer to refs. [1–6].

The first comprehensive guidance on spacers was probably Concrete Society Report CS 101 in 1989 [7]. Prior to that, it was not uncommon to use any material available on-site including bricks, tiles, broken concrete, and timber pieces to support reinforcement [4]. Another practise was to use site-made cement mortar blocks as spacers, but this practise was stopped in BS 8110-1 [8] because of poor quality control. At present, spacers in the UK should be factory manufactured, conform to BS 7973-1 [9] and placed in accordance with BS 7973-2 [10]. The general rule is that spacers should be fixed to reinforcing bars at a spacing not exceeding 50*d* or 1000 mm, where *d* is the bar size, and in staggered rows for parallel bars. Other similar recommendations are available for North American practice e.g. ACI 315-99 [11] and ACI SP-66 [12], and German practice in DIN EN 13670 [13].

All spacers (except some wire chairs for top rebars) work on the principle of supporting reinforcement from the nearest exposed surface, i.e. from the formwork or blinding. As such, spacers must interrupt the concrete cover and replace a portion of the concrete in the cover zone. Inevitably, they form a link between reinforcement and the external surface, and present a possibility of compromising the effectiveness of the cover to protect embedded reinforcement (see Fig. 2). It is

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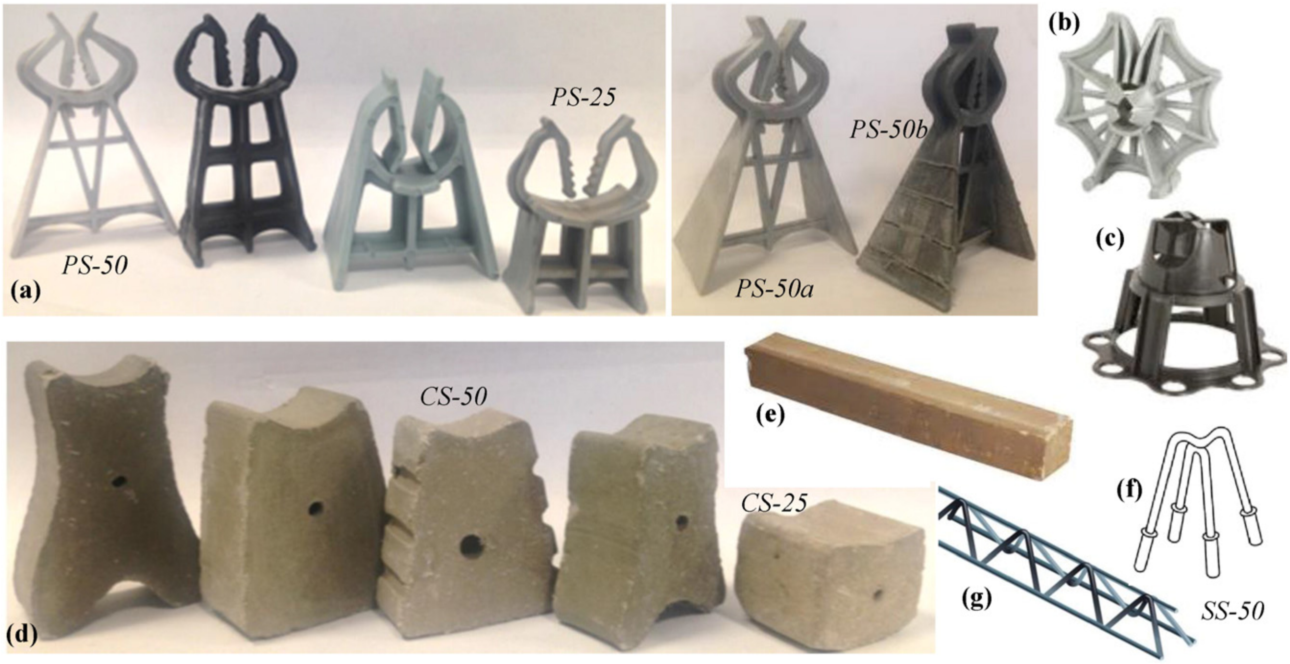

Fig. 1. Typical examples of spacers used in reinforced concrete: a) plastic clip-on "A" shaped, b) plastic wheel/circular, c) plastic tower, d) cementitious single spacer, e) cementitious line/bar spacer, f) steel wire chairs and g) steel wire continuous lattices.

reasonable to suspect that the presence of spacers potentially facilitates ingress of aggressive agents such as water, chloride, CO_2 and oxygen either through the spacer itself or its interface with concrete. If true, then spacers would act as weak links and accelerate deterioration. Furthermore, spacers are placed every metre or less along the reinforcement and are left permanently in the structure, and so a structure contains thousands of spacers and their combined effect could be significant. Indeed, several reports and field investigations have observed a link between spacers and reinforcement corrosion. Examples of such reports include refs. [1,14–22] and a common observation was that local rebar corrosion occurs at spacer locations. This was assumed to be due to either poor quality of the spacer (itself being highly porous), or the concrete near spacers (poor compaction) or the interface between concrete and spacer (e.g. debonding).

Despite concerns expressed over the effect of spacers on durability, to the best of our knowledge, there has been no systematic or fundamental research carried out on this issue. Therefore, the present work seeks to redress this by establishing the effect of several spacer types on mass transport properties and microstructure of concrete. The overall aim of this study is to enhance the understanding of how spacers influence the durability of concrete structures.

2. Experimental

2.1. Spacers

Samples of cementitious, plastic and steel spacers were requested from all leading manufacturers and distributors in the UK in order to explore the available range of products. Approximately 110 types of spacers were obtained and they varied in terms of material, height (cover size) and shape, as shown in Fig. 1. From this, 7 spacer types representing the most commonly used in construction, were selected for testing. Details of the selected spacers are given in Table 1. Bar or line spacers were rejected because these would require the preparation and testing of large concrete elements, which is impractical and probably unnecessary for the purpose of study. The selected steel spacers were continuous lattice chairs and these were sectioned at nodes into 100 mm long segments. The spacers used in this study are indicated in Fig. 1.

The porosity of cementitious spacers was obtained by measuring the mass difference from a vacuum saturated-surface dry condition to 105 °C oven-dried condition, divided by the spacer volume. Plastic spacers contain openings that might trap aggregate particles and block the movement of fresh concrete. Therefore, the openings were measured to ensure that the selected spacer had sufficiently large openings to allow the largest aggregate particles to nestle in them. Some of the plastic spacers were modified by either grinding using a 120-grit size SiC paper or by scoring four 1 mm deep notches on the main flange. The purpose of this is to increase the surface roughness of the spacer in order to improve its adhesion and bond to the concrete matrix. Prior to use, the plastic and cementitious spacers were cleaned and dried, while the steel chair segments were sand blasted to remove any rusting from the surface. The spacers were stored in the laboratory to avoid any moisture or temperature variations. The 'volume fraction' in Table 1 denotes the fraction of the disc test sample (Section 2.3) that is occupied by the spacer.

2.2. Concrete materials and mix proportions

Ordinary Portland cement CEM I was used for all mixes. Its oxide composition was 63.4% CaO, 20.8% SiO_2, 5.4% Al_2O_3, 2.4% Fe_2O_3, 1.5% MgO, 0.3% Na_2O, 0.7% K_2O, 2.9% SO_3 and <0.1% Cl. The calculated Bogue composition was 53.1% C_3S, 19.1% C_2S, 10.8% C_3A and 7.2% C_4AF. The loss on ignition, specific gravity and fineness of the cement were 2.1%, 3.06 and 291 m^2/kg respectively. Tap water was used as batch water. Thames Valley sand and gravel were used as fine aggregates and coarse aggregates respectively. The maximum particle size was 5 mm for sand. For gravel, the maximum particle size was either 10 or 20 mm. The particle size distributions of the fine and coarse aggregates are shown in Fig. 3. The sieve analysis show that the sand complied with BS 882:1992 medium grading, while the gravel complied with BS EN 12620:2002 + A1 overall grading. The specific gravity, moisture content and absorption of the aggregates are given in Table 2.

Two concrete mixes with free water/cement (w/c) ratio of 0.4 were prepared according to the proportions given in Table 3. The mixes were