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Welded, sandblasted, stainless steel corrugated bars in non-carbonated and carbonated mortars: A 9-year corrosion study

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ABSTRACT

Three different stainless steel corrugated grades (UNS S20430, S30403 and S32205) were similar welded to stainless steel bars with the same composition and dissimilar welded to carbon steel (CS). After cleaning the welding oxides by sandblasting, the reinforcements were embedded in mortar with chlorides and some of the samples were carbonated. Corrosion activity was monitored using corrosion potential (E_{corr}) and electrochemical impedance spectroscopy (EIS). After 8 years of exposure, the samples were anodically polarized. Visual evaluation of the attack was performed after another additional year of exposure. Similar welded stainless steels offer a good durability if they have been sandblasted, except for S20430 when it is embedded in carbonated mortar with chlorides. Dissimilar welded steels are active since the beginning of the exposure for both studied conditions, but sandblasting reduces the corrosion rate of CS compared to non-welded CS bars.

1. Introduction

Stainless steel reinforcements are increasingly being used as an alternative to guarantee the durability of concrete structures in corrosive environments. The alkalinity of the solution inside the pores favors the protective nature of the oxides comprised in the passive layer of the stainless steels [1–3] and reduces the risk of localized corrosion in chloride-contaminated environments [4,5].

The typical forming process of corrugated bars causes microstructural transformations in the stainless steels [6,7]. The microstructural characteristics of the reinforced bars explains the decrease of the corrosion resistance in simulated pore solutions that has been detected for stainless steels when they are corrugated [8]. The mechanical strain of the surface causes a negative effect on the stoichiometry, composition and protective nature of the passive layer on the stainless steels [9]. However, the critical chloride levels that cause pitting corrosion in corrugated austenitic and duplex stainless steels are at least 10 times higher than those of carbon steel (CS) reinforcements [10], so they are an interesting alternative to prevent corrosion problems in reinforced concrete structures.

For economical reasons, stainless steel reinforcements are only used in the most exposed areas of new structures. For instance, they could be used in bridge parts like edge beams, expansion joint sections, piers and piers tops and bridge deck soffits. That is to say, areas where the environmental chlorides would penetrate, or carbonation would take place in shorter times, as they are close to concrete surface. Welding is not the most usual method for joining reinforcing bars, but it can be the only option sometimes. Welded mesh reinforcement of stainless steel are being used extensively, both for new constructions like parking decks etc, but also in repairs of reinforced concrete (especially when the concrete cover is thin).

It has been proved that the simultaneous use of stainless steel and CS reinforcements in the same structure does not imply any risk of galvanic corrosion [10–12]. Moreover, stainless steel corrugated bars are also used to repair corroded structures, as replacements of old, damaged CS bars [13,14]. When stainless steel bars are employed to replace part of corroded CS bars, it is sometimes unavoidable to weld the stainless steel reinforcements to the rest of the structure. As constructing new concrete infrastructures implies a high amount of CO_2 emissions, boosting the repair of damaged concrete infrastructures is nowadays seen as a new way to contribute to sustainable development [15]. The use of stainless steel reinforcement in repairs avoids future restoring actions in the structure. Hence, it is interesting to achieve a good knowledge about the effect of welding on the durability of stainless steel reinforcements in concrete.

The microstructural changes in metal bars caused by welding do not endanger the mechanical performance of the structure [16]. However, tests in alkaline solutions have pointed out that welding

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can decrease the corrosion resistance of stainless steels [10–17]. Previous research carried out in simulated pore solutions suggests that the adverse effect of weldings can be more or less marked depending on the stainless steel grade: more alloyed stainless steels seem to be less welding-sensitive [17]. The pH of the alkaline solution has also proved to be a key factor to determine the corrosion resistance of welded stainless steel [18].

Solution tests have shown that the decrease in the corrosion resistance of stainless steels caused by welding is due to the formation of heat-tints during the high-temperature exposure that implies the welding procedure [4,19]. The causes suggested in the literature to justify the adverse effect of the heat-tints on corrosion behavior are diverse: formation of a Cr-poor layer [4], the chemical composition of the heat-tints [20], or the structure of the formed oxide layer and the stresses and reticular defects created in the metal–oxide interface [21].

Removing welding oxides after welding can improve corrosion resistance, but it can unlikely be restored up to levels of a non-welded corrugated stainless steel [17]. The comparative effectiveness of various methods used for cleaning the welding oxides has been reported, and sandblasting has been proposed as the most adequate method to decrease the adverse effect of welding in corrosion resistance [17].

In this work, the effect of welding in 3 different corrugated stainless steels in mortar is studied: an austenitic UNS S30403 grade (the composition with the longest and widest experience about its behavior in concrete [22,23]), an austenitic UNS S20430 grade (that has been considered interesting because of its price and its moderate corrosion resistance in synthetic pore solution testing [5,24]) and a duplex UNS S32205 grade (that has shown very high corrosion resistance in previous tests [1,25]). The 3 corrugated stainless steels were welded to similar materials and to CS bars, their welding oxides were cleaned by sandblasting, and then they were embedded in mortar and exposed to high relative humidity (90–93%). A chloride contaminated mortar was used, both non-carbonated and carbonated.

The length of the tests and the fact that they were carried out in mortar instead of in solution highlight the practical relevance of the results. The process of formation of the passive layer on steel in simulated pore solutions takes place faster than in mortar [26], so the passivation of welded stainless steels can also be slightly different from previous results in solution [17]. Moreover, if corrosion starts, there are important factors affecting the kinetic of the attack that can not be reproduced in solution tests [27].

2. Experimental

Samples of traditional austenitic S30403, low-Ni austenitic S20430 and duplex S32205 stainless steels were studied. The material was supplied by Roldan S.A. (Acerinox group, Spain) as corrugated bars typically used to reinforce concrete structures. All the stainless steel bars had been formed through a cold working process. The chemical composition and diameter of the stainless steel bars can be found in Table 1.

The stainless steel corrugated bars were similar welded to bars of the same composition (S30403–S30403, S20430–S20430 and S32205–S32205) and dissimilar welded to CS bars (S30403-CS, S20430-CS and S32205-CS). The diameters of the CS bars were always identical to those of the stainless steel bars they were going to be welded to. Their chemical compositions can be seen in Table 1.

The chosen welding method was Shielded Metal Arc Welding (SMAW) which is easily implementable in construction. The applied voltage was between 50 and 60 V, and the applied current was between 45 and 90 A. The welding electrode was OK 61.30 (UNS S30803 with a low-moisture absorption coating) for the austenitic steels and OK 67.50 (UNS S32209 with a rutile coating) for the duplex steel. The composition of the stainless steel welding electrodes and their diameters have also been included in Table 1. These welding conditions were similar to those used in previous researches in the performance of welded stainless steel reinforcements [16,17].

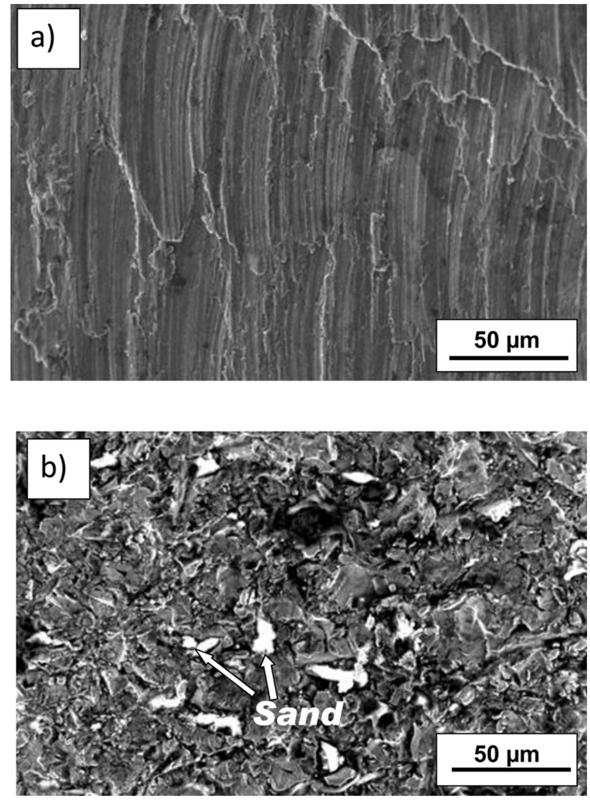

Fig. 1. SEM images corresponding to the surface of S20430 corrugated bar: (a) as-received condition; (b) after sandblasting.

All the welded samples were sandblasted to remove heat-tints. This treatment eliminated all the welding oxides formed on the stainless steel surfaces. However, it clearly modified the original topography of the bar surface, as can be checked comparing Fig. 1a with Fig. 1b. Moreover, some sand particles remained embedded in the metallic surface, as can also be seen in Fig. 1b.

The welded bars were partly immersed in mortar with a cement/sand/water ratio of 1/3/0.6. The water/cement ratio was high, as it is quite usual in experimental tests [13,27–29]. Bearing in mind that a good quality concrete can have a water/cement ratio of about 0.4, the use of this mortar samples will imply that the volume fraction of capillary porosity will be about 2 times higher after the curing period than that of good quality material [30], and nearly 3 times higher after the complete hydration of the cement [30]. However, this type of samples allows to obtain results in a reasonable period of time and can reproduce one of the conditions the stainless steel reinforcements are specially advised: light, porous concrete coatings. The cement type used to prepare the mortar was CEM II/B-L 32.5 N. The sand was standardized CEN-NORMSAND (according to the DIN EN 196-1 standard). All the samples were manufactured with 3% $CaCl_2$ in relation to the cement weight.

A schema of the samples is shown in Fig. 2. Isolating tape was used to prevent the interference of undesired, spontaneous carbonation of the mortar surface in the tests. The exposed length of the bar in mortar was always 3 cm and the welding was placed just in the middle of the length of the bar exposed to the mortar. For dissimilar welded reinforcements, the CS region was always