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Degradation relationships for the mechanical properties of corroded steel rebars

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HIGHLIGHTS

- Corrosion effects on the mechanical behavior of reinforcing steel rebars.
- Experimental investigation on the constitutive laws of uniformly corroded steel bars.
- Literature review on the mechanical behavior of locally corroded steel bars.
- Degradation laws for the mechanical properties of corroded reinforcement.

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ABSTRACT

In the present work the mechanical behavior of reinforcing steel rebars deteriorated by corrosion is investigated. The effects of both the degradation morphologies (uniform and localized) are considered. In particular, an experimental survey on artificially deteriorated steel rebars, with different diameters and subjected to different corrosion degrees, was carried out in the Laboratory of the University of Rome Tor Vergata, in order to obtain a uniform corrosion. The specimens were subsequently subjected to monotonic tensile tests in order to investigate the influence of the uniform corrosion on their constitutive relationships. On the basis of the obtained responses, decay equations for the main mechanical properties are developed. Finally, with reference to the pitting corrosion, the data presented in literature are collected and statistically analyzed for defining, in this case also, degradation equations suitable to estimate the variation of the steel mechanical properties.

1. Introduction

The principal cause of deterioration in structural concrete is related to the corrosion of the embedded reinforcement. The corrosion process mainly determines a reduction of the steel cross-section – uniform or localized on the entire reinforcement length – and a worsening of the reinforcing steel strength and ductility properties (Cairns et al. [1], Imperatore and Rinaldi [2], Rinaldi et al. [3], Apostolopoulos and Matikas [4]. Consequently, a reduction of the bearing and dissipative capacity of the structural element occurs (Castel et al. [5], Coronelli and Gambarova [6], Rinaldi et al. [3], Imperatore et al. [7,8], Meda et al. [9], Di Carlo et al. [10,11], Rinaldi et al. [12]). Two different corrosion morphologies can take place, uniform or localized ones, often associated to different degradation processes: carbonation decay (related to the diffusion of the CO_2 ions into the concrete core) and chloride attack (due to the environmental presence of chlorides), respectively. The hydration products of cement, such as the calcium hydroxide provide a high alkaline environment in concrete that activate a passivating film of iron oxide on the embedded steel bars. This environment protects the steel reinforcement bars from corrosion. Nevertheless, carbon dioxide and moisture at the surface of the concrete can react with these products to produce calcium carbonate, i.e. carbonation of the concrete. When the zone of carbonation extends to the steel, the protective action of the concrete is sharply reduced, due to the reduced PH value of the calcium carbonate. This phenomenon allows the onset of the corrosion in the reinforcing steel. The process of corrosion is accelerated if chloride ions are present. The chlorides do not react chemically in forming rust, but make easier the formation of anodic and cathodic regions in the metal. Under a chloride attack, the protective layer may be destroyed and the bar can be affected by the corrosion process. In both cases (carbonation and chloride phenomena), the steel mechanical properties will decrease. It is then worth defining steel

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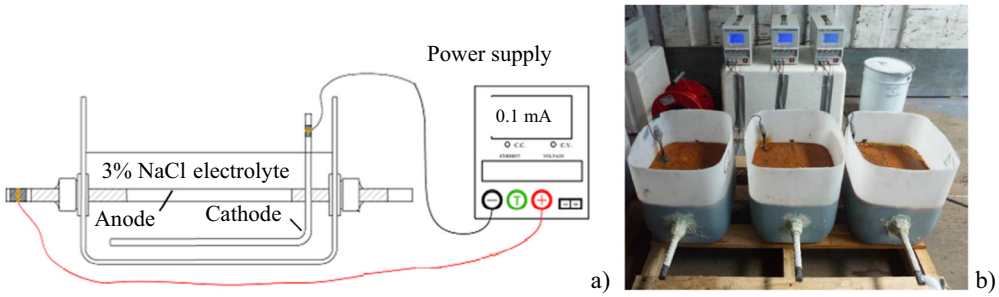

Fig. 1. Accelerated corrosion technique – electrolytic cell: a) scheme; b) experimental set-up.

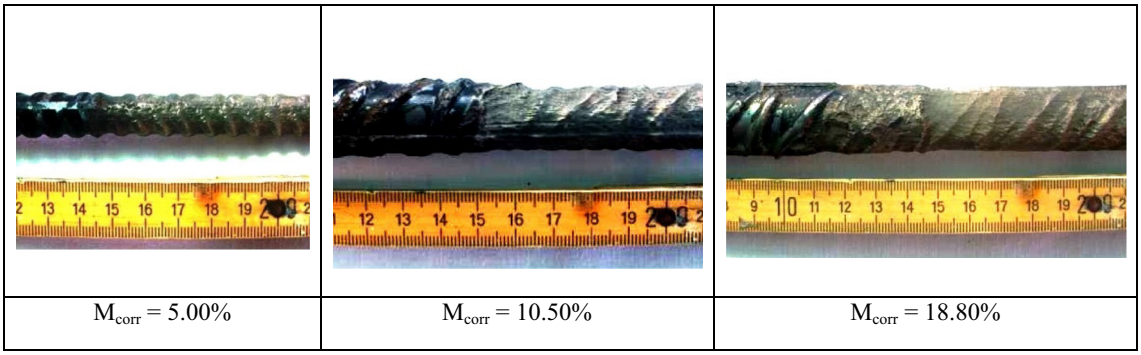

Fig. 2. Uniform corrosion on the artificial damaged specimen.

Table 1
Corrosion degrees of the artificially corroded bare reinforcements.

Ø8	$\%M_{corr}$	Ø12	$\%M_{corr}$	Ø16	$\%M_{corr}$	Ø20	$\%M_{corr}$
A1	0.000	B1	0	C1	0	D1	0
A2	8.97	B2	5.0	C2	4.4	D2	8.8
A3	10.8	B3	8.2	C3	5.3	D3	10.5
A4	19.45	B4	9.4	C4	7.9	D4	10.8
A5	20.63	B5	11.26	C5	8.5	D5	10.8
A6	21.71	B6	14.2	C6	9.0	D6	10.8
A7	22.21	B7	17	C7	10.7	D7	10.83
A8	23.45	B8	17	C8	10.8	D8	11.40
A9	23.65	B9	17.9	C9	10.90	D9	12.7
A10	25.66	B10	18.0	C10	11.00	D10	13.7
A11	25.80	B11	18.5	C11	11.00	D11	14.6
A12	28.55	B12	19.72	C12	11.55	D12	18.3
A13	29.15	B13	24.57	C13	12.20	D13	18.8
A14	53.21	B14	28.68	C14	12.48	D14	19.09
		B15	32.68	C15	12.60	D15	19.4
				C16	19.00	D16	19.79
				C17	19.00	D17	23
				C18	24.00	D18	27.69
				C19	29.00	D19	28.21
				C20	29.00		
				C21	36.00		

degradation equations for the mechanical characteristics of the corroded steel reinforcement, in order to describe the effective sectional capacity of deteriorated elements.

Even if the issue of the degradation in aged reinforced concrete structures attracts a considerable attention, corrosion effects on reinforcing steel mechanical properties are still under study.

The great part of the researches is developed with artificially corroded processes on both bare and embedded rebars. In particular, Almusallam [13] showed, through accelerated experimental tests on steel rebars with strong corrosion localization, that a slight influence on the ultimate strength occurred, but a severe reduction of the ductility took place. The Hellenic researchers assess a significant improvement to the fieldwork. The degradation of both yield and ultimate tensile strength of the reinforcing bars through artificial corrosion by salt spray was highlighted by (Apostolopoulos et al. [14]) for tempcore ∅8 mm BSt500s, by (Apostolopoulos and Papadopoulos [15] and (Papadopoulos et al. [16]) for ∅10 mm S400s, ∅12 mm B500c and S500s and by (Alexopoulos et al. [17]) for ∅12 mm BStIV from different manufacturers. Corroded bare bars and embedded reinforcements in aged concrete show significant loss in ductility (Apostolopoulos and Papadakis [18], magnified when the plastic strains increase (Apostolopoulos and Michalopoulos [19] and Apostolopoulos and Papadakis [20]. Apostolopoulos et al. [21,22] highlighted that localized (pitting)