METASTAR™ PROTECTS STEEL REINFORCEMENT (REBARS) AGAINST CORROSION

METASTAR REDUCES PORE SIZE, LEADING TO SLOWER CHLORIDE PENETRATION.

Rebars in concrete are normally protected against corrosion by a passive layer of iron oxide, only a few nanometers thick. If chloride ions dissolve in the pore water and penetrate to the re-bars, the passive layer becomes chemically unstable and begins to break down. The same thing happens if the pH of the pore water falls below about 12.5 - for example as a result of carbonation, or acid penetration.

Corrosion can be quite rapid, once the protective oxide layer round the rebar breaks down and provided that sufficient dissolved oxygen is present. The rate of corrosion depends on the electrical conductivity of the pore solution, on the pore structure (which controls the diffusion of ions and oxygen) and on the relative humidity (which controls the water content of the pores).

Corrosion of rebars results in expansive pressures which can cause cracking, spalling or even disintegration of the concrete. This naturally leads to even faster ingress of water, oxygen and salts, which combine to accelerate the corrosion process.

METASTAR & REBAR CORROSION

The beneficial effects of **MetaStar** can be summarised as follows:

- pore size is reduced, leading to slower chloride penetration
- chloride binding capacity of the paste is increased, further reducing chloride penetration
- high pH of pore water is maintained, even with excess **MetaStar**
- low carbonation rates observed in all exposure conditions
- diffusion rate of oxygen is not increased

These effects are discussed in more detail below:

FIGURE 1: **Chloride concentration profiles for non-steady state diffusion into concrete. After 1 year immersion in 0.5M NaCl** *(Data courtesy of the University of Aston. Concrete formulations as in Figure 2.)*

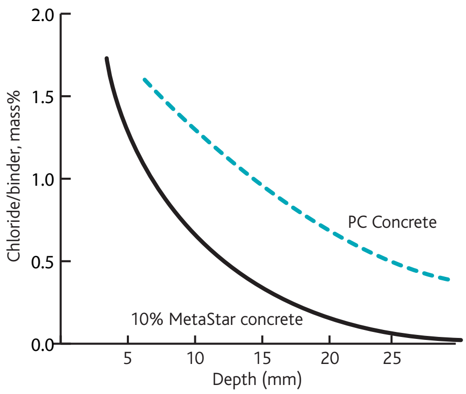

TABLE 1: **Chloride diffusion coefficients for paste and concrete, steady state and non-steady state methods, showing effect of MetaStar**

	Water/Binder	Cl⁻ Diffusion coefficient, $m^2/sec \times 10^{12}$		Method
		PC	90PC:10 MetaStar	
Paste	0.4	3.37	1.06	Non-steady state
		1.94	0.55	Steady state
	0.5	9.95	1.48	Non-steady state
		5.08	1.31	Steady state
	0.6	13.5	2.62	Non-steady state
	0.65	8.85	1.93	Steady state
Concrete	0.55	7.73	1.92	Non-steady state

Data courtesy of the University of Aston

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CHLORIDE PENETRATION

Numerous studies have shown that the diffusion rate of chloride ions in concrete is reduced, usually by a factor of 3 or more, by replacing 10% of the PC by **MetaStar**, see Figure 1 and Table 1. The time taken for salt solution to penetrate the cover layer and initiate corrosion in steel reinforcement has been measured in corrosion was detected electrochemically by monitoring the corrosion potential and the corrosion current. Figure 2 shows very directly the beneficial effects of **MetaStar** delaying the onset of corrosion.

CHEMISTRY OF PORE WATER

There is much evidence that corrosion can be initiated if the pH of the pore solution falls below about 12.5 or if the ratio of chloride ions to hydroxide ions (ie the $[Cl^-]/[OH^-]$ ratio) rises above about 3[1]. Therefore corrosion can occur if the pH decreases, or if the chloride ion concentration increases.

TABLE 2: pH of pore water in cement pastes - effect of MetaStar (BRE data)

Type of PC	pH of pore water after 365 days PC	90PC:10 MetaStar	80PC:20 MetaStar
Low alkali, 0.32 mass% Na_2O eq.	13.4	13.3	13.0
High alkali, 0.32 mass% Na_2O eq.	13.9	13.7	13.4

TABLE 3: $[Cl^-]/[OH^-]$ ratio in cement pastes - effect of MetaStar

	$[Cl^-]/[OH^-]$ in pore water 36 days	101 days
100 PC	0.51	0.41
90 PC : 10 MetaStar	0.44	0.43
80 PC : 20 MetaStar	0.57	0.56

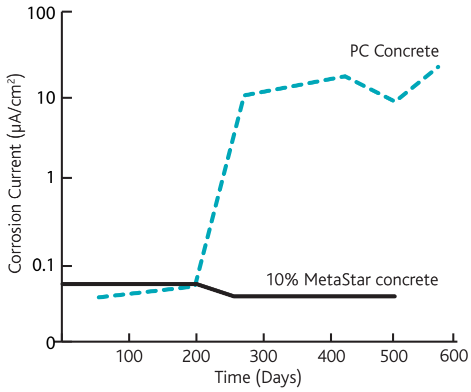
Analysis of pore water shows that the pH of pore water in **MetaStar** concrete remains above 12.5 - even in the extreme case of excess **MetaStar** (20% replacement of PC) in concrete made with low alkali PC, see Table 2. Sometimes there is a problem with chloride ions naturally present in the pore solution. The problem can be exacerbated by some pozzolanas which have the effect of increasing the $[Cl^-]/[OH^-]$ ratio. **MetaStar,** by contrast, has an ability to bind chloride ions and does not lead to a significant increase in the $[Cl^-]/[OH^-]$ ratio, see Table 3. Therefore in **MetaStar** concrete, the rebars are better able to retain their protective layer.

CARBONATION

As **MetaStar** depletes calcium hydroxide in cured concrete, it might be expected that **MetaStar** could increase carbonation. However, field experience and experiments carried out at the BRE and the University of Dundee have shown that **MetaStar** does not significantly increase the carbonation rate in concrete exposed to temperate climates, see Table 4.

FIGURE 2: Corrosion rate against time for steel bars embedded to a depth of 25mm, in PC concrete where 10 mass% of the PC is replaced by MetaStar

(Salt ponding experiments. Data courtesy of the University of Aston. Concrete formulation:
420 kg m^{-3} binder
0.53 water/binder ratio)



Laboratory simulations do show a slightly increased carbonation rate indoors (under conditions of low relative humidity), or in sheltered conditions outdoors, but this is not so relevant to rebar corrosion.

DIFFUSION OF OXYGEN

Work at the university of Aston, by Page and Chadbourn, has shown that oxygen diffusion through cement paste depends on the total porosity, and can also be reduced by pozzolanic addtions. They confirmed that **MetaStar** slightly reduces oxygen diffusion in cement paste.

TABLE 4: Carbonation depths of PC and PC/MetaStar concrete

Concrete	Exposure Conditions	Carbonation Depths PC	90PC:10 MetaStar
Binder 305 kg m^{-3} water/binder 0.55	Indoors, 65% RH, 2 yr	9.3	11
	Outdoors, sheltered, 2 yr	6.8	7.9
	Outdoors, exposed, 2 yr	4.1	2.2
Binder 285 kg m^{-3} water/binder 0.65	CEN, 65% RH, 1 yr	4.0	4.4
Binder 235 kg m^{-3} water/binder 0.79	CEN, 65% RH, 1 yr	6.0	6.7

[1] **N J Coleman & C L Page,** Cement and Concrete research, *27(1) 147-154, 1997*

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