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A discussion of the paper "Influence of pre-rusting on steel corrosion in concrete" by P. Novak, R. Mala, and L. Joska☆

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Abstract

The authors of this paper deserve to be congratulated for their study on the influence of pre-rusting on steel corrosion in concrete. The report of this kind of study is very scarce in the technical literatures. The topic of the study is very interesting as in the actual construction practice generally pre-rusted steel bars are used. We also are planning to do some study on this matter in the near future. After reading this article, we found that the authors did not provide/explain enough information/discussion related to the experimental setup and the experimental results. Further explanation on these matters will be very useful to us and also to other interested readers of the cement and concrete research journal.

1. Comments on the experimental setup

We could not find out the process of controlling the chloride level in concrete. The authors noted on page 590 that "Various chloride contents were introduced after the curing period into dry concrete blocks by way of their immersion to the sodium chloride solutions for 7 days." We did not understand the procedure behind "by way of their immersion." We are confused how the authors intruded chloride amount of 2.5% of cement weight by immersing for only a week in sodium chloride solution. Also, the definition of the machined bar was not mentioned in the paper. The process of removing the mill scale from the surface is necessary to be mentioned.

The authors also did not mention the mixture proportion of concrete, chemical composition of cement used, and also the chemical composition of the steel bars used in their study. These data will be very useful for other researchers to compare the results of this study with their own.

It is also unclear how the authors measured the polarization resistance over the steel bars exposed under different humidity conditions. How were the working electrode and the counter electrode electrically connected? The frequency of the measurements in the 4 years of exposure period was not also mentioned. Too many repetitions of the electrochemical measurements on the same specimens may also hamper the test results.

2. Comments on the results and discussions

It is concluded that for all steel bars, the corrosion was localized. However, no data or comparisons are provided for the machined, scaled, and pre-rusted steel bars on the localized corrosion. These data will be very useful. We expected that the pit depths in the case of pre-rusted bar will be less than the machined and scaled bars. With this matter, we would like to mention the conclusion of Ref. [1]. In this recent study, it is concluded that "Removing the mill scale or rust from the surface by sandblasting was beneficial in elevating the chloride threshold in alkaline solutions, although the corrosion rate of sandblasted steel after pitting initiation was higher than those of the other two groups."

It is noted in Table 1 of the paper that one concrete block with scaled bar was broken due to the corrosion of steel bars in concrete. What about the case with pre-rusted steel bar? Was the bar subjected to more uniform type of corrosion? The authors also noted that in the case of pre-rusted bar, a barrier surrounding the steel bars are created due to the rust. From this viewpoint, more anodic areas will be generated over the pre-rusted bar compared to the machined and

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Table 1
Comparison of yearly corrosion rate from electrochemical and mass loss data (pre-rusted bars)

Chloride contents (wt.% of C)	RH (%)	Rp (Ω m^2)	Current (μA/cm^2)	Corrosion rate (μm/year)[a]	Corrosion rate (μm/year)[b]
< 0.05	60	22	0.118	1.4	5
	80	4	0.650	7.5	3
	90	2	1.300	15.0	3
	100	2	1.300	15.0	4
0.42	60	61	0.043	0.5	≦ 1
0.43	70	5	0.520	6.0	2
0.37	80	4	0.650	7.5	4
0.39	90	5	0.520	6.0	2
0.53	100	2	1.300	15.0	5
2.14	60	18	0.144	1.7	2
2.39	70	5	0.520	6.0	11
2.44	80	4	0.650	7.5	10
2.71	90	2	1.300	15.0	8
2.65	100	1	2.600	29.9	5

[a] From polarization resistance data.
[b] From physical observation.

Table 2
Comparison of yearly corrosion rate from electrochemical and mass loss data (scaled bar)

Chloride contents (wt.% of C)	RH (%)	Rp (Ω m^2)	Current (μA/cm^2)	Corrosion rate (μm/year)[a]	Corrosion rate (μm/year)[b]
< 0.05	60	34.0	0.076	0.9	0.2
	80	42.0	0.062	0.7	≦ 0.1
	90	38.0	0.068	0.8	≦ 0.1
	100	48.0	0.054	0.6	≦ 0.1
0.42	60	69.0	0.038	0.4	≦ 0.1
0.43	70	40.0	0.065	0.7	0.2
0.37	80	50.0	0.052	0.6	0.2
0.39	90	57.0	0.046	0.5	0.2
0.53	100	32.0	0.081	0.9	0.2
2.14	60	24.0	0.108	1.2	2.4
2.39	70	6.0	0.433	5.0	10.6
2.44	80	3.0	0.867	10.0	13.3
2.71	90	1.0	2.600	29.9	61.6
2.65	100	4.0	0.650	7.5	1.9

[a] From polarization resistance data.
[b] From physical observation.

scaled bar. It will also reduce the macro-cell activities and enhance the micro-cell activities and finally will contribute to the less degree of localized corrosion (if oxygen permeability is considered constant thorough the cover concrete). On the other hand, very localized formation of anodic area will create deep pits in the case of the bar with machined and scaled bar as concluded in Ref. [1].

Sulfates are confirmed over the pre-rusted steel bars before being embedded in concrete. We believe that it may influence the corrosion of steel bars with or without the presence of chlorides. Sulfate may transfer to the sulfuric acid, which is highly corrosive to both steel and concrete [2]. The authors quoted that sulfates can hardly act as a major stimulator of corrosion in an environment containing chlorides. We did not understand the reason. More explanation or some references will be useful.

The authors assume that the transport of OH^- through rust increases pH under the rust, but not on the level where the spontaneous passivation occurs. We would like to note that the hydroxyl ions may neutralize due to the presence of sulfate in the rusts. It will certainly hamper the formation of passivation film.

The acceleration of corrosion of the pre-rusted steel bars is quoted in Ref. [3] due to the self-reduction of Fe_2O_3 to Fe_3O_4. The influence of this process will be significant at the early age of exposure. The authors noted only the average data in the course of 4 years of exposure.

The authors also noted some general data of corroded area over the steel bars. However, we are not sure how the authors measured the corroded area over the pre-rusted steel bars.

In Table 1, average mass-loss corrosion rate, polarization resistance, and free corrosion potential are noted. No relation between electrochemically measured average depth of corrosion and average value of mass-loss corrosion was provided. We found that there is a significant difference between the estimated depth of corrosion from the electrochemical data (the polarization resistance data of Table 1 was converted to the depth of corrosion) and the physically measured depth of corrosion as noted in Tables 1–3. The calculation methods are given below.

The corrosion rate is calculated from the polarization resistance data as below [4]:

$$x = 0.0115 I_{av} t \alpha$$

where x is the depth of corrosion (mm), I_{av} is the average corrosion current density (μA/cm^2), which can be calcu-

Table 3
Comparison of yearly corrosion rate from electrochemical and mass loss data (machined bar)

Chloride contents (wt.% of C)	RH (%)	Rp (Ω m^2)	Current (μA/cm^2)	Corrosion rate (μm/year)[a]	Corrosion rate (μm/year)[b]
< 0.05	60	142	0.018	0.2	≦ 0.1
	80	202	0.013	0.1	0.2
	90	194	0.013	0.2	≦ 0.1
	100	152	0.017	0.2	≦ 0.1
0.42	60	148	0.018	0.2	≦ 0.1
0.43	70	106	0.025	0.3	≦ 0.1
0.37	80	109	0.024	0.3	≦ 0.1
0.39	90	129	0.020	0.2	0.3
0.53	100	104	0.025	0.3	0.2
2.14	60	52	0.050	0.6	1.1
2.39	70	13	0.200	2.3	7.4
2.44	80	14	0.186	2.1	7
2.71	90	8	0.325	3.7	5.5
2.65	100	36	0.072	0.8	1.6

[a] From polarization resistance data.
[b] From physical observation.

lated from the polarization resistance data as mentioned below, t is the time (year), and α is a pit concentration factor. The value of pit concentration factor α varied from 4 to 8 [5]. In this case, it was assumed to be in unity as the authors did not explain the localized corrosion data. Corrosion current density (I) is calculated from the following equation [4]:

$$I = B/\mathrm{Rp}$$

where $B = 0.026$ V, and Rp is the measured polarization resistance times the polarized area (Ω cm^2). Here, the total area of the bar is considered as the polarized area.

We again appreciate the authors' effort on this research topic. The authors' comments will be highly appreciated on the raised issues related to this study.

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