 DOI: 10.1002/maco.200905236

The effects of various formwork surfaces on the corrosion performance of reinforcing steel in concrete

S. Subaşı*, M. Arslan and G. Durmuş

In this study, the effects of various formwork surfaces on the corrosion performance of reinforcing steel in concrete were examined. For this purpose, seven formwork surfaces from populus nigra, pinus silvestris, steel sheet, and four of plywoods were prepared. Three of the plywood formworks were covered with different geotextile liners and drainage channel and holes were drilled on their surfaces. One of the plywood formworks having no processes on its surface was for control. Reinforcing steels were first embedded in formworks and then the concrete was poured. The samples were exposed to corrosion in a way of settling them in 5% NaCl solution. We tested the corrosion potential and bonding strength of the samples. Later, the mass loss and tensile strength were measured on reinforcing bars that were pulled out from the concrete. The chloride content and pH values were also tested on concrete powders. The results indicated that drained-lined formwork (F5 with TB50 + F613 geotextile liner) compared to steel sheet (F4 undrained and unlined) gave 16% lower corrosion and 68% higher bonding strength on reinforcing bars embedded samples, 73% lower mass loss and 4% higher tensile strength on reinforcing bars, and 70% lower chloride content and 4% higher pH on concrete powders. In addition, it was found that the corrosion strength of reinforcing steels in concrete could be increased if drained-lined formworks were utilized.

1 Introduction

Formwork, which has the basic abilities of supporting new concrete, shaping and smoothing the surface, influences the durability of the near surface concrete [1, 2]. It is known that some factors such as: (a) Formwork surfaces; (b) Concrete mixing and casting; and (c) Formwork set-up and joining points are important variables in relation to the formation of surface defects. The concrete cover protects concrete and reinforcements from environmental attacks and the quality of the surface skin on any concrete structure is a critical factor in determining the long-term durability of the structure [3]. Concrete mix water is also an important factor for the service life of the reinforced concrete building elements [4]. Reinforcing corrosion is induced primarily by the ingress of chlorides into uncontaminated concrete [5, 6]. In many exposure conditions the main long-term risk of damage for reinforced concrete arises from carbonation-induced corrosion of the reinforcing steel [7–9]. Carbonation reduces the overall pH of the concrete in the reinforcement cover zone, eventually resulting in the depassivation of steel and the consequent on-set of corrosion [10]. Most of the researches to improve the properties of the concrete surface focused on controlled permeability formwork (CPF). CPF provides a concrete structure with a dense skin that is capable of protecting steel reinforcement, and the concrete core, from the attack of aggressive elements (Fig. 1) [11]. Controlled permeability formwork is applicable to many different areas, but is mostly used in aggressive environments where ingress of aggressive elements would be a major problem. The main application areas are: marine structures, bridges and bridge structures, water reservoirs, sewage plants, and underground construction [12]. Several studies have shown that CPF prolongs serviceability and reduces maintenance requirements, particularly in aggressive environments [13–15].

On the other hand, many researches gave importance on preventing reinforcing corrosion that was decreased significantly when mineral additives such as fly ash, silica fume, and rice husk ash are used in the concrete instead of cement [16–18]. It is also indicated that the values of tensile strength of reinforcing that was exposed to corrosion in the ratio of 20% and over decreased by the ratios of 20 and 30%. Present brittle fracture in the researches occurred due to changes in the mechanical properties of the reinforcing exposed to corrosion in the reinforced concrete element [19–21].

S. Subaşı, M. Arslan, G. Durmuş
Duzce University, Technical Education Faculty, Construction Department, Duzce 90380 (Turkey)
E-mail: serkansubasi@duzce.edu.tr

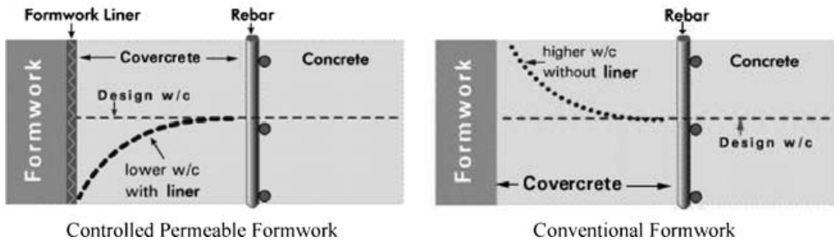

Figure 1. The low w/c ratio obtained with CPF in the concrete cover zone provides a superior durability of the concrete structure

Furthermore, it is known that carbonation and chloride penetration, which are effective on reinforcement corrosion, occurred rarely in concretes that were poured with CPF than the conventional formworks [22–24].

The timber and plywood are generally used in the production of formwork surfaces [25]. The impermeable formwork surfaces that are not water absorptive result in an increase in cavities on the concrete surface. Cavities decrease the strength of concrete due to easier penetration of harmful active materials. Use of CPF makes the concrete more dense, smooth, and resistant to atmospheric conditions by decreasing surface faults [26]. The aim of this study is to investigate the impacts of various formwork surfaces on reinforcing corrosion in concrete.

2 Experimental details

2.1 Materials

Formwork surface materials, formwork surface liners, ready-mixed concrete, and reinforcing elements were used in this study. Formwork surface materials are first class populus nigra, second class pinus silvestris, 20 mm thick plywood, and 3 mm thick steel sheet. The properties of formwork surface materials were detailed in Table 1. Formwork surface liners are SB20, BL20, TB50, and F613 geotextiles and the properties of surface liners were given in Table 2. Ready-mixed concrete was C20 (Table 3) including Type-I cement that is used in the production of ready-mixed concrete. The chemical properties of cement are shown in Table 4. Reinforcing elements were 20 mm diameter smooth surfaced reinforcing bars consistent of AISI 1012 Standard (Table 5).

Table 1. Properties of formwork surface materials

Material	Density (kg/m^3)	Humidity (%)	Annual ring thickness (mm)	Thick (mm)
Populus nigra	397	12.10	5.09	20
Pinus silvestris	485	12	2.75	20
Plywood	672	10.90	–	20
Steel sheet	–	–	–	3

Table 2. Properties of formwork surface liners

Geotextile Code	Weight (g/m^2)	Tensile Strength (N)	Break-off Stretch (%)	Penetration Resistance (N)
SB20	200	286	29	225
BL20	200	260	30	220
TB50	500	1260	56	915
F613	130	208	15	190

2.2 Preparation of formworks and samples

A total of 70 formworks were prepared including ten pieces for each formwork. These formworks were set up for concrete samples with $80 \times 80 \times 340$ mm dimensioned reinforcing as illustrated in Fig. 2. A total of seven formworks were prepared

Table 3. Mixture proportion of concrete

Concrete class	C20
Dmax	16 mm
Natural sand (0–4 mm)	550 kg
Crushed fine aggregate (4–8 mm)	560 kg
Crushed coarse aggregate (8–16 mm)	700 kg
W/C ratio	0.48
Water	190 liter
Type I Cement	400 kg
Air Content	1.5%
Slump	12 cm
Admixtures	No

Table 4. Chemical properties of cement

SiO_2 (%)	25.91
Al_2O_3 (%)	6.68
Fe_2O_3 (%)	3.30
CaO (%)	53.8
MgO (%)	1.52
SO_3 (%)	2.84
Cl (%)	0.009
Na_2O (%)	0.85
K_2O (%)	0.95
Loss on ignition (%)	3.47
Amount of pozzolanic material (%)	14.77
Initial set (h:min)	2:52
Final set (h:min)	6:00
Volume stability (mm)	6
Specific gravity (g/cm^3)	2.99
Specific surface (cm^2/g)	3244
Compressive strength (N/mm^2)	
2nd day	16.8
7th day	28.8

Table 5. Chemical composition of reinforcing bar

C	Mn	P	S	Mo	Nb	V	Fe
0.12	0.51	0.02	0.04	0.04	<0.002	<0.001	<98.06

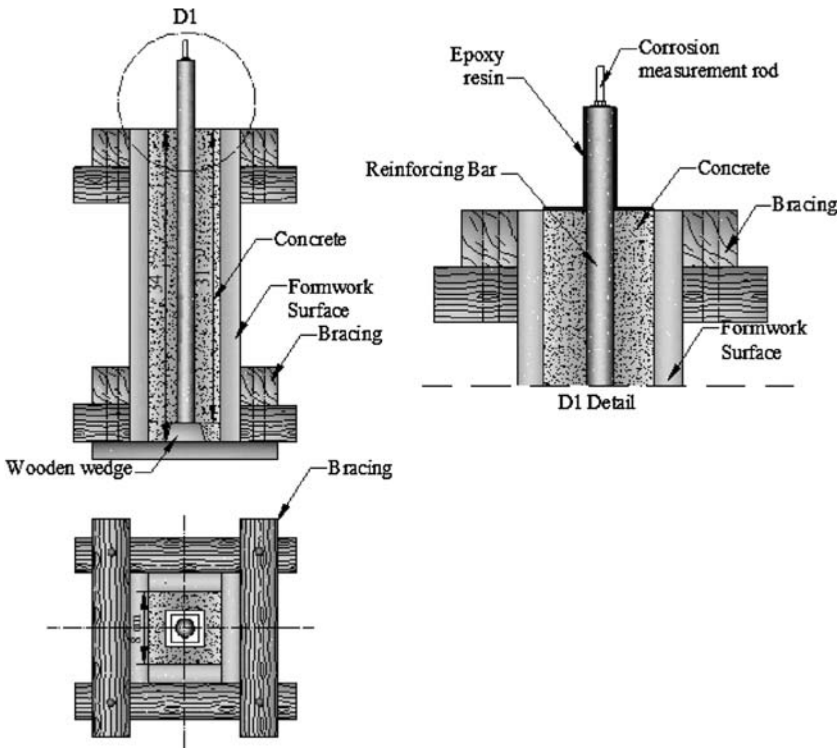

Figure 2. Project of formwork

using populus nigra, pinus silvestris, steel sheet, and four plywoods having drainage channels and holes on the surfaces of three of them as illustrated in Fig. 3. The formwork surfaces having drainage channels and holes were covered with geotextile liners by order of TB-50 + F-613, SB-20, and BL-20. The other formwork surfaces were oiled with mineral oil and essential concentrated formwork oil before pouring concrete. Formwork codes and properties of formwork surfaces are given in Table 6.

Thick smooth steel bars (20 mm) were embedded in each formworks leaving 30 mm thick corrosion portion. The wooden wedge that have been put on the base of steel bars for centering were removed after pouring concrete and filled up with hot bitumen. The parts of the steel bars staying out of the concrete were covered with epoxy resin.

All the samples were cast from a single batch of concrete. Compaction of concrete within the formwork was achieved by using vibrating table. The formwork was removed 48 h after casting and the concrete samples were stored for 28 days in the cure room, which was conditioned at $22 \pm 2\,^{\circ}C$ temperature and 95% relative humidity.

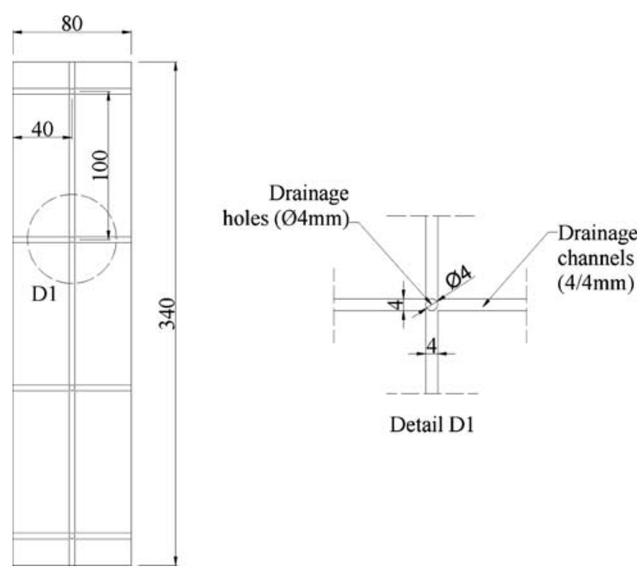

Figure 3. Drainage channels and holes on formwork surface

Table 6. Formwork codes and properties of formwork surface

Formwork code	Formwork surface material	Formwork liner	Drainage chanels and holes
F1	Populus nigra	No	No
F2	Pinus silvestris	No	No
F3	Plywood	No	No
F4	Steel sheet	No	No
F5	Plywood	TB50 + F613	Yes
F6	Plywood	SB20	Yes
F7	Plywood	BL20	Yes

Table 7. Schedule of experimental study

Formwork		Samples		Type of experiment	Test period (Month)
Code	Number	Type	Number		
F1	10	Reinforced steel bars embedded in concrete	100	Corrosion potential	0, 1, 2, 3, ..., 13th
F2	10	Reinforced steel bars embedded in concrete	100	Bonding strength	13th month
F3	10	Pieces of reinforcing steel bars	2	Optical microscopy	13th month
F4	10	Reinforcing steel bars	100	Mass loss	13th month
F5	10	Reinforcing steel bars	100	Tensile strength	13th month
F6	10	Powder from concrete	10	Chloride content	13th month
F7	10	Powder from concrete	10	pH value	13th month

2.3 Test methods

After 28 days concrete cure process, the procedures listed below were carried out:

- The corrosion potential measurement of reinforcing bars for 13 months,
- the bonding test of the reinforcing bars after the corrosion measurements,
- photographing the cross sections of reinforcing bars by examining with optical microscopy,
- measurement of corrosion weight losses of the bars of which bondings were measured,
- tensile strength test of the bars of which corrosion weight losses were measured,
- measurement of chloride content and pH of the concrete samples that were smashed after the bonding test.

The procedures belonging to experimental studies and the process are given in Table 7.

2.3.1 Corrosion potential test

Corrosion acceleration process was carried out by storing the concrete 2 days in 5% NaCl solution, and 28 days at $20 \pm 5\,°C$ temperature in laboratory conditions. This corrosion acceleration period was repeated for 13 times. Corrosion potential measurements were started right after cure process of 28 days. These measurements were made at each corrosion acceleration period when the samples were saturated to 5% NaCl solution. Corrosion potentials were implemented consistent with ASTM C 876 Standard by half-cell potential tool with $Cu/CuSO_4$ electrode (Fig. 4) [27].

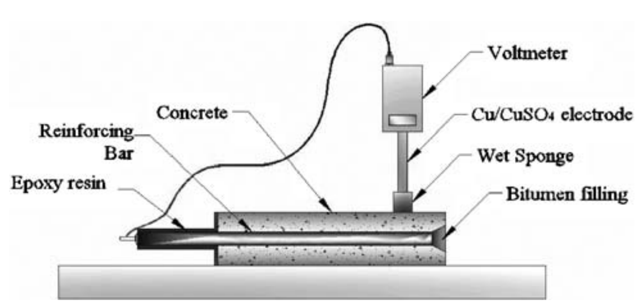

Figure 4. Schematic details of the half-cell potential test

2.3.2 Bonding (pull out) test

Bonding strength was measured on the samples that were used first to measure the corrosion potential. The load speed that was consistent with ASTM C 234-91a Standard was 0.075 kN/s in the measurements (Fig. 5) [28]. The bonding strength was calculated using following formula:

$$\tau_b = \frac{P_1}{\ell_b(\phi \cdot \pi)} \tag{1}$$

In the formula the abbreviations states the meanings listed below:

τ_b Maximum bonding strength (MPa),
P_1 Maximum axial tensile load (kN),
$\emptyset$ Reinforcement diameter (mm),
ℓ_b The length of the reinforcing touching the concrete (mm).

2.3.3 Evaluation of rust by optical microscopy

The minimum and maximum bonding strength values for F4 and F6 formworks were chosen for evaluation. Sample of 15 mm width section was prepared from the steel bars. The samples were mounted in bakelite in order not to defect corrosion layer on them. One surface of the samples that symbolizes width section was polished with diamond polishing machine. The samples were etched with 2% nital (2% nitric acid, 98% wood alcohol) in order to specify the difference between oxide layer and main

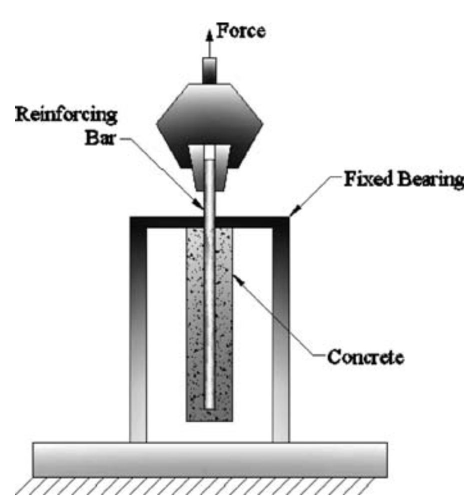

Figure 5. Schematic details of the bonding test

metal by photography. The oxide layer, occurred on the samples by being exposed to these processes, was analyzsed by optical microscopy and also photographed.

2.3.4 Determination of weight loss of reinforcing because of corrosion

The method proposed in the ASTM G1-03 Standard was used for the determination of weight loss of reinforcing. The known weights of reinforcing bars that were pulled out from the concrete were cleaned with Clarke solution which is a mixture of 1000 ml HCl, 24 g Sb_2O_3, and 71.3 g $SnCl_2.2H_2O$ [29]. The weights of cleaned bars were measured with 0.01 g sensitivity. Weight losses were calculated as corrosion loss using the following formula.

$$W_L = \frac{m_1 - m_2}{m_1} \times 100 \qquad (2)$$

In the formula the abbreviations state the meanings listed below:

W_L Weight loss (%)
m_1 First weight (g)
m_2 Last weight (g)

2.3.5 Tensile strength test of reinforcing bar

Tensile strength test was carried out on reinforcing bars, which were cleaned from rusts, consistent with the fundamentals clarified in TS 138 EN 10002-1 ''Metallic materials – Tensile testing – Part 1: Method of test at ambient temperature'' [30].

2.3.6 Chloride content and pH test

Chloride content test was carried out in consistence with TS EN 1744-1 on powder samples obtained from the pieces after pulling out the reinforcing in the concrete beginning from the reinforcing touching surface to 1 cm depth. Standard solutions were prepared by powder samples, of which pH measurements had been made, with pure water. Solutions were obtained by dissolving 2.5 g powder in 25 ml pure water. The pH measurements were carried out on the solutions prepared by digital pH meter [31, 32].

3 Result and discussion

The data obtained were analyzed statistically by the variance analysis (ANOVA) and the Duncan test (Table 8).

3.1 Corrosion potentials

It is observed that corrosion potential was gradually increased from 0 to 13 months (Fig. 6). Tests showed that after 3 months all

Table 8. The results of the variance analysis and the Duncan tests

Experiments		Formwork code and comparison differences							Formwork	
		F1	F2	F3	F4	F5	F6	F7	Code	Means
Corrosion potential 13th month (mV vs. CSE)	F1					S*	S*		F4	−663.9
	F2					S*	S*		F1	−661.4
	F3					S*	S*		F3	−654.7
	F4					S*	S*		F2	−648.8
	F5	S*	S*	S*	S*				F7	−607.5
	F6	S*	S*	S*	S*				F6	−571.5
	F7								F5	−558.0
Bonding strength (MPa)	F1					S*	S*	S*	F4	1.473
	F2					S*	S*	S*	F2	1.861
	F3				S*	S*	S*	S*	F1	1.869
	F4			S*		S*	S*	S*	F3	2.407
	F5	S*	S*	S*	S*			S*	F7	3.329
	F6	S*	S*	S*	S*			S*	F5	4.235
	F7	S*	S*	S*	S*	S*	S*		F6	4.333
Mass loss of reinforcing bars (%)	F1			S*	S*	S*	S*	S*	F4	1.435
	F2				S*	S*	S*	S*	F1	1.183
	F3	S*			S*	S*	S*	S*	F2	1.159
	F4			S*		S*	S*	S*	F3	0.952
	F5	S*	S*	S*	S*				F7	0.564
	F6	S*	S*	S*	S*				F6	0.445
	F7	S*	S*	S*	S*				F5	0.393
Tensile strength of reinforcing bar (MPa)	F1					S*	S*		F4	432.29
	F2					S*	S*	S*	F2	435.57
	F3					S*	S*		F1	437.50
	F4			S*		S*	S*	S*	F3	441.13
	F5	S*	S*	S*	S*				F7	442.86
	F6	S*	S*	S*	S*				F5	445.29
	F7								F6	447.63

(a)S*: There is significant differences between means (at the level of $p \leq 0.05$).

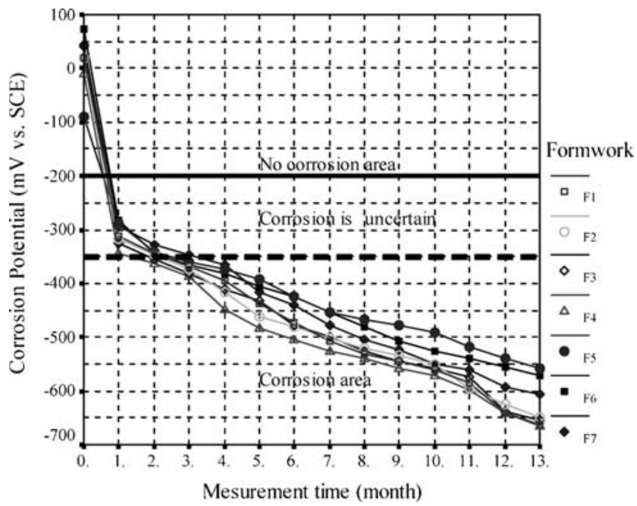

Figure 6. Half-cell potential measurements of reinforcing steel bars embedded in concrete samples during corrosion test

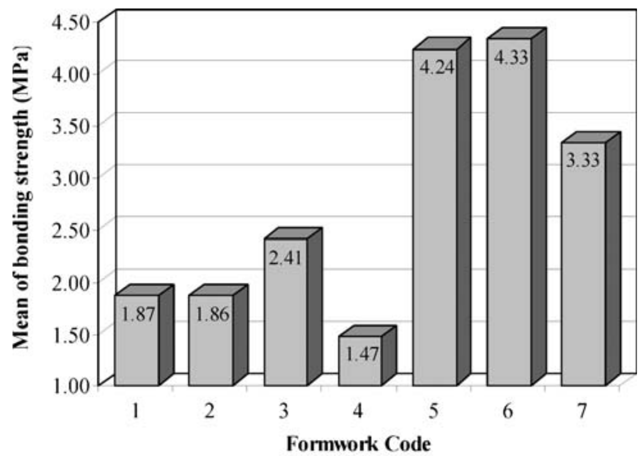

Figure 7. Bonding strength of reinforcing steel bars embedded in concrete samples

samples passed over the corrosion area as indicated ASTM C876 ($p < 0.1$).

Corrosion potential of samples measured after the accelerated corrosion test gave −661.4 mV (F1), −648.8 mV (F2), −654.7 mV (F3), −663.9 mV (F4), −558 mV (F5), −571.5 mV (F6), and −607.5 mV (F7) (Table 8). According to the statistical analysis and evaluations of the test results, it was observed that:

- The corrosion potential measured for undrained-unlined (F1, F2, F3, and F4) formworks were not significant ($p > 0.05$);
- the corrosion potential measured for drained-lined (F5, F6, and F7) formworks were also not significant ($p > 0.05$)
- undrained-unlined formwork (F4) gave the maximum corrosion potential (−63.9 mV);
- undrained-unlined formwork (F2) had the minimum corrosion potential (−648.8 mV) compared to other undrained-unlined formworks;
- drained-lined formworks (F5 and F6) were significantly different compared to the other formworks ($p < 0.05$);
- drained-lined formwork (F5) had the minimum corrosion potential (−558.0 mV) compared to all other samples.

Drained-lined formworks (F5, F6, and F7) were compared to the undrained-unlined formworks and the first had lower corrosion potential. It was observed that drained-lined formwork (F5) gave 16% less corrosion potential than undrained-unlined formwork (F4).

3.2 Bonding strength

Table 8 displays the statistical results for bonding strength and Figure 7 shows the average bonding strength values for various formworks.

Bonding strength tests on reinforcing steel bars embedded in concrete samples gave 1.87 MPa (F1), 1.86 MPa (F2), 2.41 MPa (F3), 1.47 MPa (F4), 4.24 MPa (F5), 4.33 MPa (F6), and 3.33 MPa (F7). According to the statistical analysis and evaluations of the test results, it was observed that:

- The bonding strength of F3 and F4 was significantly different ($p < 0.05$) when undrained-unlined formworks were compared;
- one of the undrained-unlined formwork surface, F4 had the minimum (1.473 MPa) but the other, F3 had the maximum (2.407 MPa);
- undrained-unlined (F1, F2, F3, and F4) formworks significantly differ from drained-lined (F5, F6, and F7) formworks ($p < 0.05$);
- although, the bonding strength of drained-lined formworks of F5 and F6 were not significantly different ($p > 0.05$), there was a significant difference between these formworks and F7 formwork ($p < 0.05$);
- undrained-unlined formwork of F4 had the minimum (1.37 MPa), while drained-lined formwork of F6 had the maximum (4.333 MPa) bonding strength.

The reinforcing bars were pulled out from the samples that the concrete was divided into two parts. Reinforcing bars left some

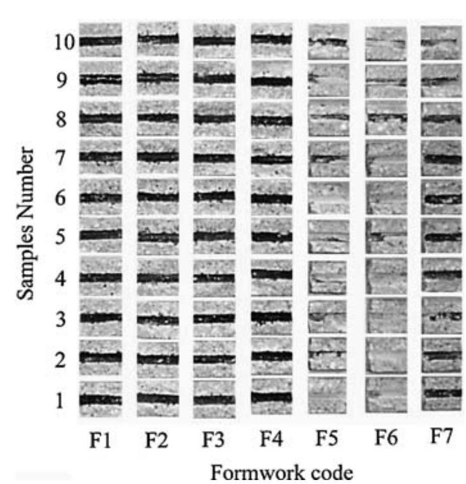

Figure 8. Rusts on the concrete samples

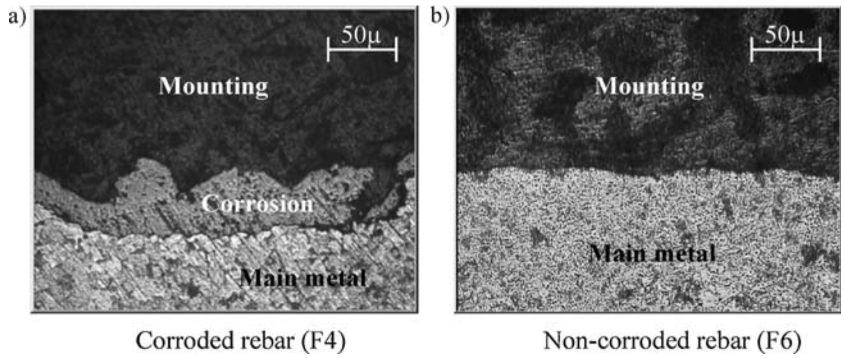

Figure 9. Microscopic images of reinforcing bars

rusts on the concrete samples that depend on the corrosion level (Fig. 8).

It was observed that drained-lined (F5, F6, and F7) formworks had higher bonding strength compared to the other samples. Drained-lined formwork of F6 gave 68% higher bonding strength than undrained-unlined formwork of F4. On the other hand, it was shown in Figure 8 that lower corrosion rusts were observed on concretes of F5 and F6. This finding supports higher bonding strength data observed by F5 and F6 formworks.

3.3 Evaluation of rust by optical microscopy

Optical evaluations were made for samples having the highest (F4) and the lowest (F6) corrosion potential. The images taken from undrained-unlined (F4) and drained-lined (F6) formworks using optical microscopy illustrated in Figure 9 showed the higher corrosion potential of the sample of F4 is due to the higher exposure of corrosion of the reinforcing bar (Fig. 9(a)). A certain thickness of corrosion layer was seen on F4 formwork, but there was no corrosion layer on F6 formwork. This finding supports the other obtained data regarding the corrosion as well.

3.4 Evaluation of corrosion by mass loss

Statistical analyses regarding the mass loss due to corrosion on reinforcing bars are given in Table 8. Figure 10 displays the average mass losses.

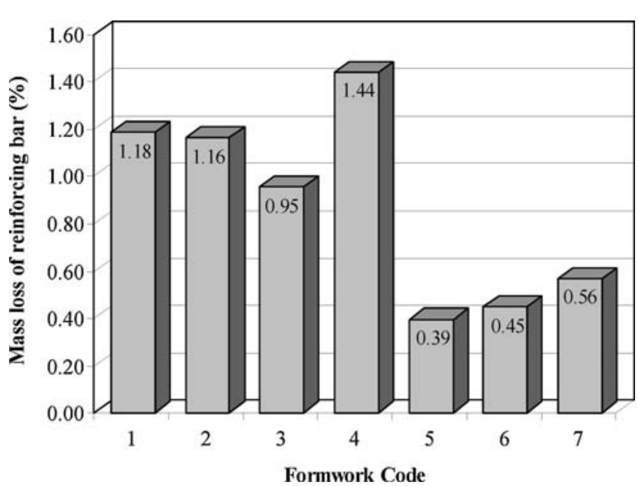

Figure 10. Mass loss on reinforcing bars

As shown in Figure 10, the mass loss of 1.18% (F1), 1.16% (F2), 0.95 (F3), 1.44% (F4), 0.39% (F5), 0.45% (F6), and 0.56% (F7) was observed for various samples (Table 8.). According to statistical analysis and evaluations of the test results of mass losses, it was observed that:

- Undrained-unlined formworks of F1 and F3 and of F3 and F4 were significantly different ($p < 0.01$);
- when undrained-unlined (F1, F3, and F4) formwork and drained-lined (F5, F6, and F7) formwork were compared there were significant differences between samples;
- drained-lined formwork samples (F5, F6, and F7) had lower mass losses than the other formworks;
- There were no significant differences between drained-lined formworks (F5, F6, and F7);
- undrained-unlined formwork of F4 gave the maximum mass loss (1.44%) while drained-lined formwork of F5 had the minimum (0.39%);
- drained-lined formwork of F5 had 73% lower mass loss compared to the undrained-unlined formwork of F4.

According to regression analysis it was shown that there is a quadratic $y = 2.46 - 0.880X + 0.0931X^2$ model equation between mass loss of reinforcing bar and bonding strength (Fig. 11).

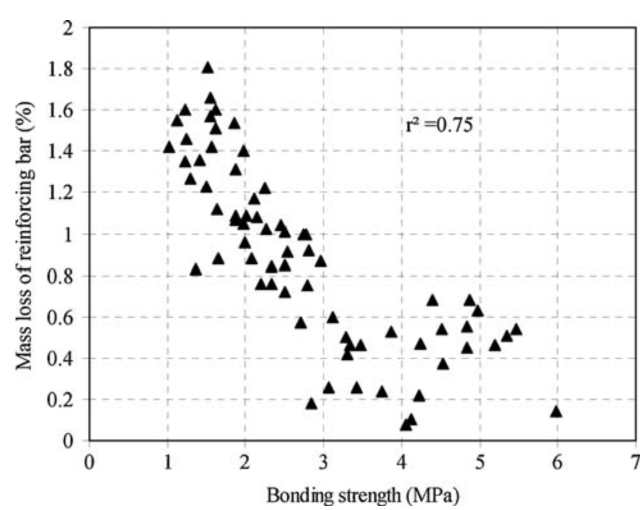

Figure 11. Relation between bonding strength and mass loss on reinforcing bars

3.5 Tensile strength of reinforcing bars

Tensile strength tests resulted in 437.50 MPa (F1), 435.57 MPa (F2), 441.13 MPa (F3), 432.29 MPa (F4), 445.29 MPa (F5), 447.63 MPa (F6), and 442.86 MPa (F7) for reinforcing steel bars (Table 8). Figure 12 displays the average tensile strength. According to statistical analysis and evaluation of the tensile strength test results, it was observed that:

- There were significant differences between F3 and F4 formworks of undrained-unlined formworks ($p < 0.05$);
- When drained-lined (F5, and F6) and undrained-unlined (F1, F2, F3, and F4) formworks were compared, there were significant differences for tensile strengths ($p < 0.05$);
- Undrained-unlined formwork of F4 had the minimum (432.29 MPa) while drained-lined formwork of F6 had the maximum (447.63 MPa) tensile strength.

It could be concluded from the findings that drained-lined formworks (F5, F6, and F7) had higher tensile strength than undrained-unlined formworks (F1, F2, F3, and F4). in addition, drained-lined formwork of F6 had 4% higher tensile strength compared to the undrained-unlined formwork of F4.

3.6 Chloride content and pH value

Chloride content and pH data on concrete surfaces were tested and results are given in Table 9.

According to the evaluations of the chloride content test data, it was observed that:

- Drained-lined formwork of F5 had the minimum chloride content (0.27%), while undrained-unlined formwork of F4 had the maximum;
- drained-lined formwork of F5 gave 70% lower chloride content than undrained-unlined formwork of F4.

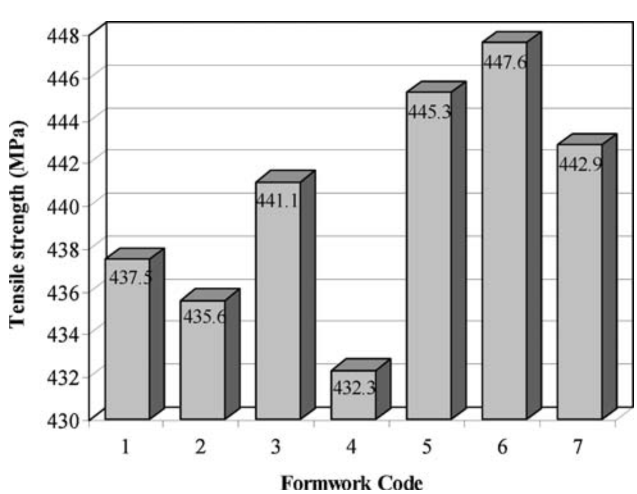

Figure 12. Tensile strength of reinforcing bars

Table 9. pH value and chloride content of samples

Formwork code	Chloride content %	pH values	Order of magnitude	
			According to chloride content	According to pH values
F1	0.81	12.07	F4	F4
F2	0.72	12.00	F1	F2
F3	0.76	12.01	F3	F3
F4	0.89	11.83	F2	F1
F5	0.27	12.31	F7	F7
F6	0.56	12.21	F6	F6
F7	0.74	12.05	F5	F5

According to the evaluations of the pH data, it was observed that;

- Drained-lined formwork of F5 gave the maximum pH (12.31), while undrained-unlined formwork of F4 had the minimum (11.83);
- drained-lined formwork of F5 had 4% higher pH than undrained-unlined formwork of F4.

4 Conclusion

Seven formworks, four of them are undrained-unlined and three of them drained-lined were prepared in this study. A total of 70 concrete samples including reinforcing steel bars were produced using prepared formworks. Corrosion potential, bonding strength, mass loss, tensile strength, chloride content, and pH tests were carried out on the samples. The impacts of various formwork surfaces on reinforcing corrosion and parameters that cause corrosion were evaluated with the data obtained. According to the statistical analysis and evaluations, it was observed that:

1) Drained-lined formworks had higher corrosion resistance than undrained-unlined formworks;
2) formwork of F5 covered with TB50 + F613 liner, and formwork of F6 covered with SB20 liner resulted in the best performance for all tested properties;
3) when drained-lined formwork of F5 covered with TB50 + F613 liner was compared to the undrained-unlined steel sheet formwork of F4, F5,

    - was exposed to lower corrosion of 16%,
    - had 68% more bonding strength,
    - had 73% less reinforcing mass loss,
    - had 4% more reinforcing break-off stretch,
    - had 70% less chloride content, and
    - had 4% more pH value.

5 References

[1] W. R. Anthony, D. J. Stainer, *Concrete Construction* **1988**, *33*, 452.
[2] M. Arslan, *J. Institute Sci. Technol. Gazi Univ.* **1995**, *9*, 615.

[3] P. C. Kreijger, *Mag. Conc. Res.* **1978**, *39*(140), 122.
[4] P. L. Owens, *Concrete Int.* **1988**, *13*, 68.
[5] K. C. Clear, *V.3. Report F.H.W.A.-RD-76–70*, FHWA, U.S. Department of Transportation, 1976, 67.
[6] A. Shamsad, B. Bishwajit, W. Rajeen, *ACI Material J.* **1997**, *94*, 311.
[7] L. J. Parrott, Cement Concrete Association Report., C-1:1–0987, 1987.
[8] L. J. Parrott, *Mag. Conc. Res.* **1994**, *46*(166), 2.
[9] D. Meyer, J. Triebert, W.-D. Schulz, *Mater. Corros.* **2006**, *56*, 334.
[10] R. K. Dhir, S. Y. N. Chan, P. C. Hewlett, *Mag. Conc. Res.* **1989**, *41*(148), 137.
[11] P. G. Malone, *Technical Report SL-99–12*, US Army Corps of Engineers, Washington, October, **1999**.
[12] M. G. Sorensen, *Concrete* **2003**, *37*, 4.
[13] M. J. McCarthy, A. Giannakou, *Cement Conc. Res.* **2002**, *32*(3), 451.
[14] W. Price, *Controlled permeability formwork*, CIRIA Publication C511, 94, **2000**.
[15] M. McCarthy, A. Giannakou, R. Jones, *Mater. Struct.* **2001**, *34*, 566.
[16] W. Sun, Y. Zhang, S. Liu, *Cement Conc. Res.* **2004**, *34*, 1781.
[17] J. Hou, D. D. L. Chung, *Corros. Sci.* **2000**, *42*, 1489.
[18] *ACI 222.3R-03 Design and construction practices to mitigate corrosion of reinforcement in concrete structures*, American Concrete Institute, **2003**.
[19] A. A. Almusallam, *Const. Building Mater.* **2001**, *15*, 361.
[20] Ch. Alk. Apostolopoulos, M. P. Papadopoulos, Sp. G. Pantelakis, *Const. Building Mater.* **2006**, *20*, 782.
[21] Ch. Alk. Apostolopoulos, D. Michalopoulos, *Mater. Corros.* **2007**, *58*, 5.
[22] J. Sousa Coutinho, *Cement Conc. Compos.* **2003**, *25*(1), 51.
[23] M. Arslan, *Construction Building Mater.* **2001**, *15*(4), 149.
[24] A. K. Suryavanshi, R. N. Swamy, *Cement and Concrete Research* **1997**, *27*, 1047.
[25] M. Arslan, O. Şimşek, S. Subaşı, *Construction and Building Materials* **2005**, *19*, 319.
[26] M. Arslan, S. Subaşı, G. Durmuş, *3rd International Advanced Technologies Symposium*, August, Ankara **2003**, *4*, 355.
[27] *ASTM C876-91 Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete*, ASTM Book of Standards Volume: 03.02, **1999**.
[28] *ASTM C234–91a, Standard Test Method for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel*, **2000**.
[29] *ASTM G1–03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*, ASTM Book of Standards Volume: 03.02, **2003**.
[30] *TS 138 EN10002-1 ''Metallic materials – Tensile testing – Part 1*: Method of test at ambient temperature'', Turkish Standards Institution, **2004**.
[31] *TS EN 1744-1, Tests for chemical properties of aggregates-Part 1*: Chemical analysis, Turkish Standards Institution, **2000**.
[32] *ASTM C1152/C1152M-04e1 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete*, ASTM Book of Standards Volume: 04.02, **2004**.

(Received: January 6, 2009) W5236
(Accepted: February 18, 2009)

