Extending the Life Span of Concrete Buildings in Germany/Middle Europe by Applying an External Thermal Insulation System

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ABSTRACT

In Germany, around 50% of trade volume in the building and construction industry is in the field of repair and modernization. The volume in the field of the repair of outer walls contributes a quota of approximately 20%. This 20% quota is almost completely dedicated to large panel buildings with sandwich walls. A common damage is corrosion of the reinforcement in the facing layers of the outer walls due to an insufficient concrete cover. It has been proven that the progress of corrosion can be stopped by a thermal upgrade of the sandwich walls (e.g., by applying an additional curtain wall or a similar thermal insulation system on the exterior of the existing walls). At the same time, permeable joints and crack damage can be efficiently controlled by this measure. This method of repairing walls is being applied in Germany with success; it is only valid for regions with a climate similar to that of Germany (moderate region) and is not effective in regions with a hot and humid climate.

INTRODUCTION

The housing situation in the Federal Republic of Germany has an urgent demand for modernization or rehabilitation. Currently, this circumstance causes about 50% of the complete volume of trade in the German building and construction industry to be produced by the field of repair and modernization. This is a trend that is increasing. In this connection, the outer walls show a decisive quota; with regard to the whole repair volume, the outer walls constitute a quota of approximately 20%. This 20% quota, in turn, is almost completely made up by large panel buildings. The outer walls for these buildings have been carried out as sandwich walls for the most part, as shown in Figure 1. In northern Europe, no drainage layer is being carried out in such wall constructions.

The reasons for the damage are:

- Corrosion of the reinforcement in the area of the facing layers due to an inadequate concrete cover (Figure 2). Furthermore, observations have shown that the reinforcement in the structural inner load-bearing layer under normal conditions never corrodes.
- Cracks in the facing layers (Figure 3) and partly powdering wall surfaces.
- Thermal bridges due to an inadequate constructive con-

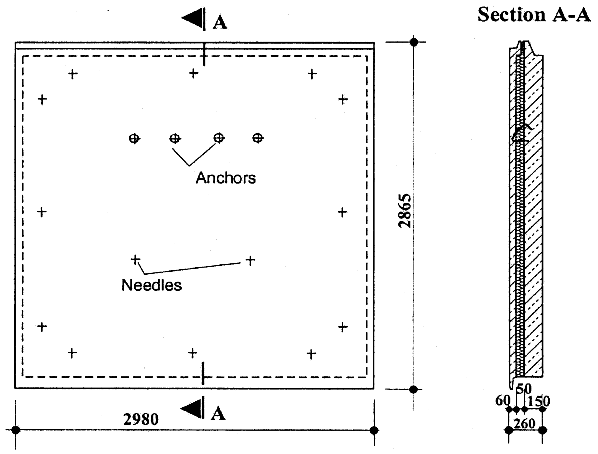

Figure 1 *Typical concrete sandwich wall element.*

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Figure 2 *Corrosion damage due to low concrete cover.*

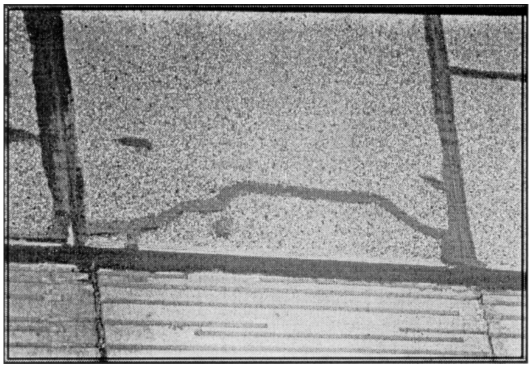

Figure 3 *Cracks in the weather protection layer of a concrete sandwich wall.*

dition of the walls with the result of mold-fungal formation (Figure 4). Further reasons for the formation and growth of mold fungus can be excluded (e.g., penetrating moisture from the joints, high interior relative humidity with air penetrating to the exterior of the buildings causing concentrated condensation, or exterior rain absorption of the outer facing layer).

- Deficient joint sealing (Figure 5).

RESTORATION OF EXTERIOR WALLS BY "THERMAL UPGRADE"

Through a "thermal upgrade" (e.g., by applying an ETIC [external thermal insulation system] [Figure 6] or applying an insulated curtain wall construction [Figure 7] on the three-layer exterior wall [sandwich wall]), the thermal protection of the walls will be improved considerably. Cracks and leaky joints are covered effectively too. Furthermore, the corrosion protection of the walls will be improved considerably.

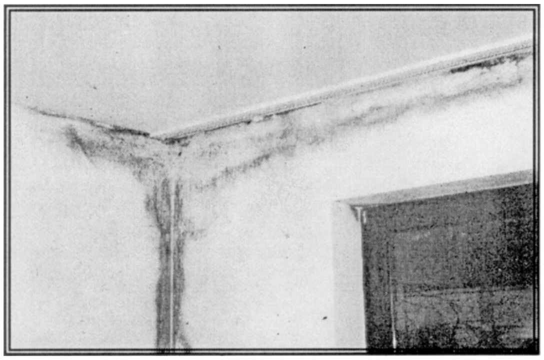

Figure 4 *Mold-fungal formation.*

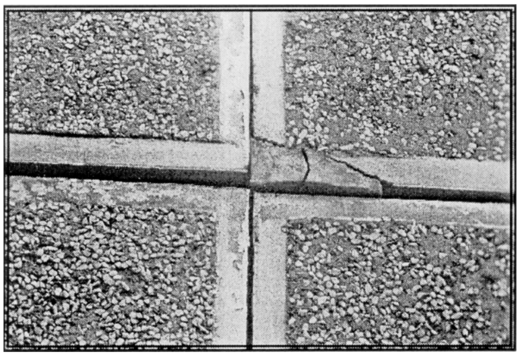

Figure 5 *Deficient joint.*

The concept of stopping the corrosion process by an additional thermal insulation system is based on the fact that corrosion of reinforcement steel in concrete requires the following three conditions simultaneously:

1. The passivation of the steel surface in the concrete is neutralized by carbonation,

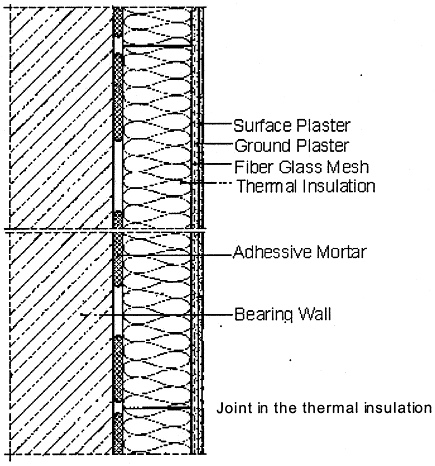

Figure 6 *Sandwich walls with subsequently applied ETICS.*

2. oxygen reaches the steel, and
3. concrete contains enough moisture in order to act as an electrolyte.

While conditions 1 and 2 will not be influenced by application of an ETIC or curtain-wall system, the concrete will be kept dry enough that corrosion of steel cannot progress at the previous rate (due to a lack of moisture that is necessary to act as an electrolyte).

It has been proven that corrosion of the reinforcement can only take place if the moisture content in the carbonated concrete exceeds 80% relative humidity. This result was found as follows:

The corrosion of reinforcement depends on the surrounding air and its relative humidity. In order to obtain reference values for the corrosion of reinforcement embedded in carbonated concrete, reinforcement bars were stored according to DIN 50014 at room temperature and different relative humidities. The reinforcement bars were not embedded in concrete. At relative humidities of more than 60%, measurable loss of the mass due to corrosion was observed. This result coincided with those given in Marquardt (1991).

The corrosion process of steel in carbonated concrete is different from the corrosion process in the atmosphere because

- the penetration of oxygen in concrete is obstructed,
- carbonated concrete has a higher PH value as the normal industrial atmosphere, and
- the formation of electrolytes in the hygroscopic concrete is different from that on the unprotected steel surfaces.

The formation of an electrolyte (an electrical conducting liquid salt solution) in carbonated concrete is generally possible in middle and northern Europe due to the climatic conditions. Usually a sufficient electrolyte volume is present due to the weather conditions outside of the wall.

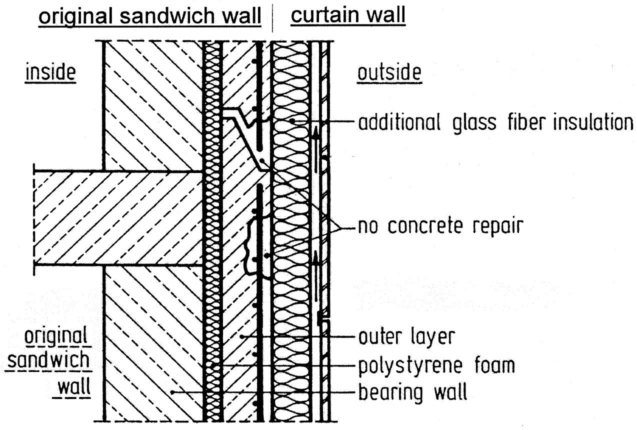

Figure 7 *Concrete sandwich wall repaired using additional curtain wall.*

To clarify the corrosion behavior of reinforcement in carbonated concrete, porous concrete specimens (W/Z = 0, 8) were manufactured and stored in an atmosphere with a relative humidity of 52% over a saturated salt solution of sodium bicarbonate in a CO_2 concentrated atmosphere for carbonation. Due to the high CO_2 concentration, the carbonation of the specimens was accelerated and, due to the low relative humidity (52%), the corrosion of steel was prevented. Further tests have shown that the structure of pores of the artificially carbonated concrete is the same as that for naturally carbonated concrete. Afterward, the carbonated specimens were stored at temperatures between 18°C and 26°C and relative humidities of 60%, 70%, 80%, and 90% (equilibrium relative humidity). After 7, 14, 28, and 56 days, as well as after half a year and after two years, the specimen were opened and the condition of the reinforcement considering mass loss was examined. It was proven that significant mass losses due to corrosion only occur at relative humidities of greater than or equal to 80%. The initial mass loss in the examined specimens can be explained by the carbonation process. Carbonation causes a reduction in alkalinity. When the PH value is less than nine, corrosion sets in if the critical moisture is $\varphi \geq 80\%$ RH. This initial corrosion of the reinforcement did not lead to any damage (cracking, bond reduction, etc.).

The protection of concrete through exterior thermal insulation reduces the relative humidity to only 50% to 70% (Figure 8), so that by application of additional thermal insulation on the exterior wall, the corrosion process can be effectively slowed down. This principle of corrosion protection has been proven efficiently in laboratory and field tests as follows:

The measured relative humidities in the concrete layers—with and without subsequently applied thermal insulation—lay in the range of 40% to 70%. The measuring time was 2.5 years. Instationary calculations had, as a result, relative humidities laying between 45% and 65% after about three years of drying out. The correlation between measured and calculated results can be regarded as good enough (Figure 9).

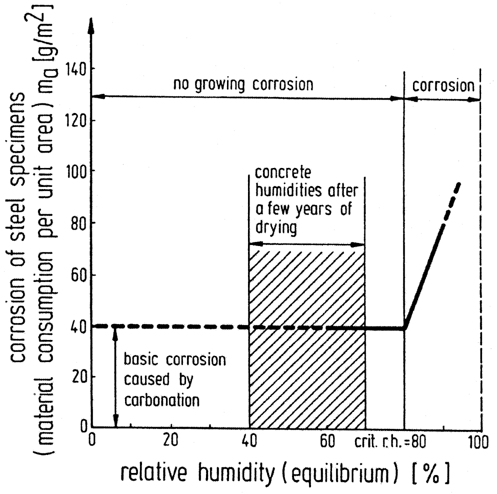

Figure 8 *The critical moisture content for corrosion of the reinforcement rod in the carbonated concrete is φ = 80% to 90% relative humidity.*

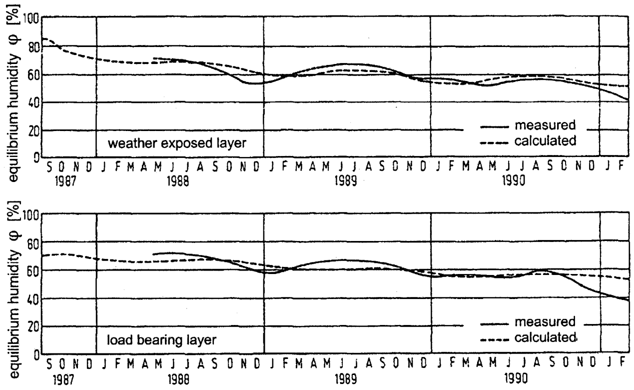

Figure 9 *Measured and calculated relative humidities in the weather exposed concrete layer and the load bearing concrete layer of a sandwich wall element with an additional curtain wall.*

In the conducted measurements, the initial values of relative humidities were between 60% and 70%. In order to investigate the drying-out behavior of higher initial relative humidities, the drying-out behavior for this case was examined numerically. The simplified result is shown in Figure 10. According to this figure, the outer concrete layers of sandwich walls dry out rapidly under the critical value of 80% in the case that a diffusive cladding (curtain wall) is applied. The drying out is also rapid if a mineral thermal insulation composite system is applied.

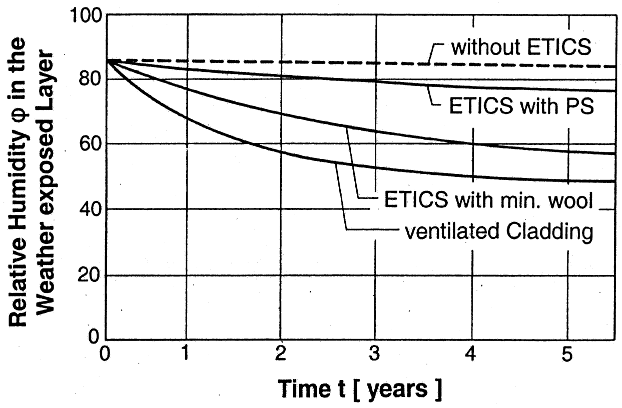

Figure 10 *Drying behavior of the facing layer of concrete sandwich walls with supplementary application of ETICS or curtain-type exterior wall constructions in relation to walls without any application (upper curve).*

TABLE 1
Average Climate Values (Germany)

Month	Interior temp. [°C]	Interior relative hum.	Exterior temp. [°C]	Exterior relative hum.	Hours
Oct.	21.2	49	10.1	82	744
Nov.	20.0	44	4.6	86	720
Dec.	19.8	38	0.9	88	744
Jan.	19.4	33	-0.7	85	744
Feb.	19.7	35	-0.3	81	672
March	20.6	38	3.3	76	744
April	20.5	42	8.6	70	720
May	21.5	41	13.3	64	744
June	22.6	54	17.5	67	720
July	22.9	54	18.5	69	744
Aug.	23.0	57	17.9	74	744
Sept.	22.1	50	14.7	77	720
Year	21.1	40	9.1	77	8760

For the case when a thermal insulation made of polystyrene with synthetic resin plaster is applied, the drying out takes much longer.

The thickness of thermal insulation (mineral wool and polystyrene) in Germany is usually between 8 and 12 cm. The calculations for the drying behavior were conducted for German/middle European climates (Table 1).

For regions with similar climatic conditions, the beforementioned conclusions/results are compatible. For other

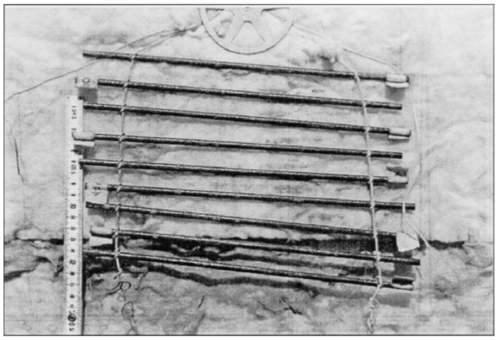

Figure 11 *Corrosion of a reinforcement steel after 18 months; it was inserted in the ventilation space of a curtain wall.*

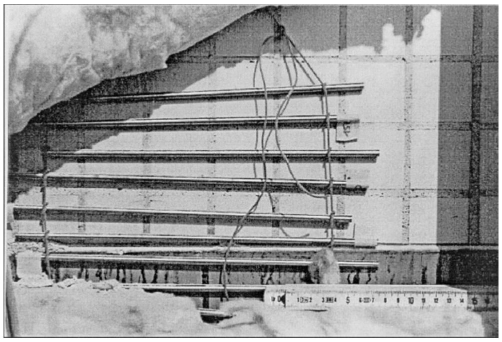

Figure 12 *This is the same situation as in Figure 11, but here the steel was placed behind the thermal insulation in the “dry” region.*

climatic conditions, especially in warm, humid climates, these results do not apply.

In order to elucidate the protection efficiency of a subsequently applied ETIC, or curtain-wall system, polished reinforcement rods were inserted in the ventilation space of a curtain-wall construction. After a period of 15 to 18 months, the unprotected reinforcement rods were considerably corroded (Figure 11). For comparison, the same kind of reinforcement rods were installed within a curtain-wall construction, only they were placed behind the thermal insulation. After 15 months, the steel showed no signs of corrosion and the surface remained metallically blank (Figure 12). Even after a further observation period of approximately three years, the situation still remained unchanged.

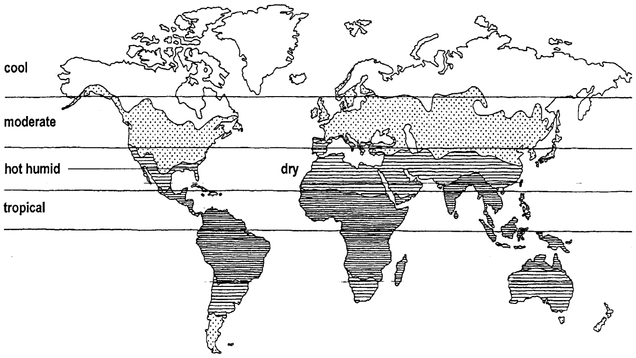

Figure 13 *World map of climatic regions.*

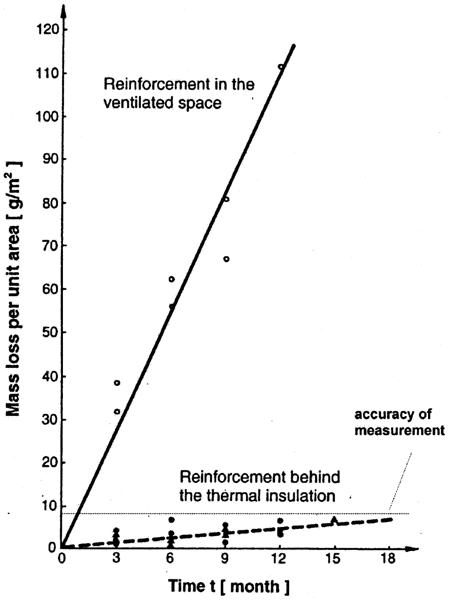

Figure 14 *Reduction of corrosion on reinforcement steel on a completed building during a 1.5 year observation period—the steel, which was placed behind a thermal insulation, did not show any signs of corrosion, whereas the protected steel was considerably corroded.*

CONCLUSIONS

Through measurements and calculations, it was determined that the corrosion process in concrete sandwich walls, with subsequently applied curtain wall constructions, was slowed down due to a relatively fast-drying process of the facing layer below a moisture content of 80% relative humidity. The drying process of concrete sandwich walls, which were provided with ETICS, was not as fast as the drying process of the relatively diffusion-permeable ventilated exterior curtain walls. The results of the investigations are only valid for regions with a climate similar to that of Germany (moderate regions, Figure 13 and Table 1).

In summary, it can be said that efficient corrosion protection of the reinforcement in the facing layer can be achieved by exterior application of thermal insulation measures on concrete sandwich walls. This was certified by measurements on completed buildings (Figure 14).

ECONOMIC EFFICIENCY OF A SUBSEQUENTLY APPLIED THERMAL INSULATION SYSTEM

An amortization of the investment costs for the subsequently applied thermal insulation system, in terms of energy conservation, within a reasonable period of time (t = 10 to 15

Figure 15 *Restored building.*

years), is not given based on the current energy costs. In Germany, 1 kWh ≈ 0.30 DM, the cost of ETICS ≈ 100 DM/m², and curtain-wall systems ≈ 200 DM/m².

But given the fact that a large number of existing buildings show signs of severe damage on their exterior wall surfaces (plaster detachment on masonry buildings and especially corrosion damage on the outside of sandwich walls), there is the possibility on the one hand to efficiently cover the crumbly plaster with a supplementary thermal insulation and, on the other hand, to efficiently stop the corrosion process of the reinforcement in concrete sandwich walls. Evaluations of economic efficiency with amortization periods of approximately 4 to 17 years were calculated (Assmann et al. 1988) in which both a low level of damage through corrosion and a high level of damage through corrosion were considered.

Figure 15 shows an example of a building that was restored according to this method.

SUMMARY

For the rehabilitation of exterior walls of buildings, special technologies were developed. It has been proven that, especially during rehabilitation of exterior walls of large panel buildings, a large number of currently known damage can be efficiently reduced through thermal upgrade. The corrosion progress of corroded reinforcement rods in facing layers of sandwich walls can, in this manner, be significantly slowed down. At the same time, permeable joints, crack damages, and powdering surfaces can be efficiently controlled.

Considering the costs, it has been shown that, especially in cases of high-level corrosion damages, an amortization of the investment costs for the subsequently applied thermal insulation system, considering energy conservation based on the current energy costs, is given in less than four years.

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