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EFFICIENCY AND DURABILITY OF REPAIR AND MAINTENANCE SYSTEMS FOR CRACKED EXTERNAL RENDERINGS

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Abstract

Wider, and thus harmful cracks (crack width approximately over 0.2 mm) may occur frequently in renderings. The cracks have various causes, e.g. due to structural conditions and unequal displacement of the rendering and the backing. In order to ensure the operability of the building shell, in particular protection against environmental influences, such cracked renderings must be repaired. Multiple systems are proposed, however their efficiency can not be measured sufficiently.

The substantial mechanical properties (tensile strength, creeping, relaxation, crack bridging capacity) of repair systems which are applied to a rendering can be determined with a recently developed test set-up and test specimens before or after artificial or natural weathering.

Key Words

rendering, crack bridging capacity, repair and maintenance systems, durability

1 Introduction

A plastered facade is the protective external skin of the building. Wide, and thus harmful cracks occur with relative frequency – especially in renderings. The types of crack appearing and their causes are many and varied. A large number of rendering repair and maintenance systems are available for restoring the operative capacity of a cracked plaster facade. The efficiency of such systems however has long not been possible to evaluate, if at all, to an adequate extent. In an earlier Research Project (Schubert and Krechting 1999), carried out at the Institute of Building Materials Research (Aachen University) with the development of a laboratory test method suitable for use in practice, essential basic principles were drawn up for the evaluation

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of the efficiency in regard of the crack bridging capacity and tests made on a number of repair and maintenance systems normally found on the market.
The long-term efficiency of the rendering repair and maintenance systems is considerably influenced by climatic stress and by internal time-dependent stress reduction (relaxation). These influences on the efficiency are largely unknown. In particular organic modified building materials are especially exposed to environmental effects, particularly UV radiation, in which important material properties, such as above all the crack bridging capacity, may be rendered considerably more ineffective.
The aims of a recently carried out Research Project (Schubert, Schmidt and Förster 2004) at the Institute of Building Materials (Aachen University) were to test the influences on durability under climatic stress and of relaxation behaviour on the efficiency of rendering repair and maintenance systems and the devising of a calculation concept for the efficiency of repair and maintenance systems to include all the important influences in the form of an easy to apply proof by calculation, so that the optimum repair and maintenance system suitable can be selected according the specific case of cracking.

In various publications calculation proposals are derived for the design of crack bridging coatings (normally surface protection systems for concrete components). Essential variables influencing the efficiency of the coating systems are the permissible deformation of the coating, the coating thickness of the systems and the elasticity or shear modulus of the coatings. The mechanical properties normally have to be determined here on the coating itself, i.e. for example by testing on the free film.
The application of the calculation proposals presented of rendering repair and maintenance systems is generally conceivable. The determination of the essential properties – also as a function of the system used – has to be made with different test methods, in some cases still to be developed. Every individual characteristic value is subject to a range of scatter, so that a theoretical estimate of the crack bridging capacity on a design rating is dependent on a) the scatter of the test parameters and b) the accuracy of the calculation proposal. Another factor in this procedure is a possible influence of the rendering to be used for the coating, on the repair and maintenance system and its mechanical properties, which are not considered.
The above considerations led to the determination of the material characteristic values of the rendering repair and maintenance systems within the scope of this Research Project in the applied state, so that the efficiency of the systems can be determined directly by one test. A theoretical estimate by this means is not therefore absolutely imperative. In the determination of the strength and tensile deformation at fracture in the short-term test and of the relaxation or creep behaviour before and after artificial or natural weathering, the results can be compared with long-term tests in crack bridging. With the development of a test method suitable for use in practice a direct conclusion can also be drawn on the efficiency of the systems taking into account also the relaxation behaviour and the long-term durability.

2 Development of a test method

The testing principle essentially corresponds to a test situation developed in an earlier Project (Schubert and Krechting 1999) the Institute of Building Materials Research, Aachen (ibac). The experimental equipment, control of the test stands and the measurement and control equipment had to undergo considerable further development however, inter al. owing to the significantly higher demands for accuracy – especially for the relaxation tests. In order to store the test specimens for outside weathering, specimens had to be designed which can be transported after coating. Fig. 1 and Fig. 2 show the design of these test specimens. The test specimen consists of a basic body of cement-rendering and the repair and maintenance system, which is applied via a

crack produced according to plan at the intended point of fracture in the middle of the basic test body.

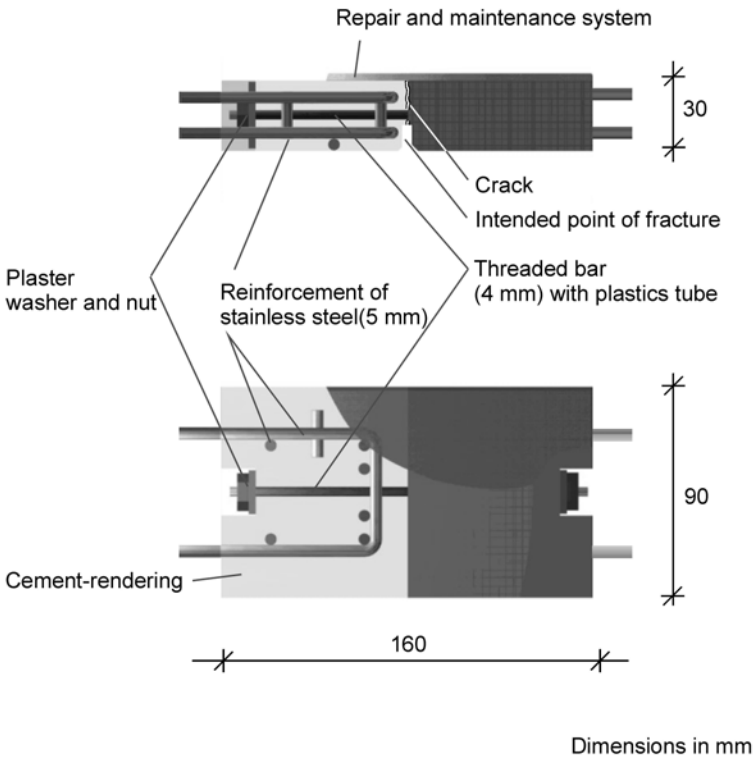

Figure 1 Schematic design of a test specimen with reinforcement cage

For fixing the crack the two halves of the test specimen are stressed before coating with the help of a plastics covered threaded bar in the middle of the specimen. In some cases the basic test specimens were reinforced by using specially made "reinforcing cages" of stainless steel reinforcing bars, in order to ensure adequate strength of the basic test specimen.

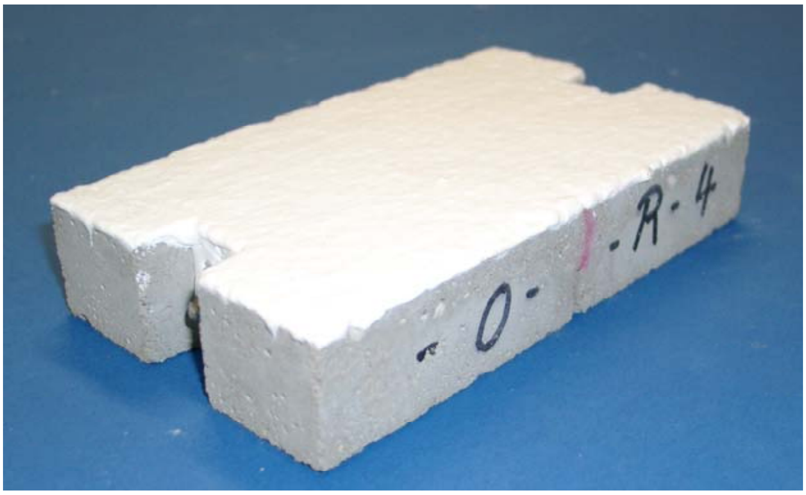

Figure 2 Test specimen with applied System D (without reinforcement cage)

The new developed test specimens are glued onto an initial load application device, consisting of a horizontally sliding and a firmly fixed steel plate. The crack in the basic test specimen is to be found directly above the vertical joint assembly of the steel plates. The load introducing device operates via a lifting arm system, which permits the maximum applicable load and also variation of the rate of application. The bottom lever arm is articulated and attached to be vertically displaceable to the horizontally movable steel plate. The load introduction is made in the middle of the applied repair and maintenance system and is adjustable in height, so that no vertical forces nor moments are introduced into the coating at the crack. On both sides of the top lever arm water containers are suspended over wire cables and deflection rollers. The load application is made by changing the water level by means of precision valves, in which the sliding load application plate is moved in a horizontal direction. The deformation (crack expansion) is measured by means of displacement transducers. The forces introduced for the expansion of the steel plates are determined by means of load cells above the water containers. The forces and deformations are recorded by a computer, which also controls the pumps for changing the states of water according to the type of stress or specimen size (tensile strength, relaxation behaviour, creep behaviour or crack bridging). Fig. 2 shows the design of the recently developed test set-up. Altogether 6 such test states shown in Fig. 3 were constructed.

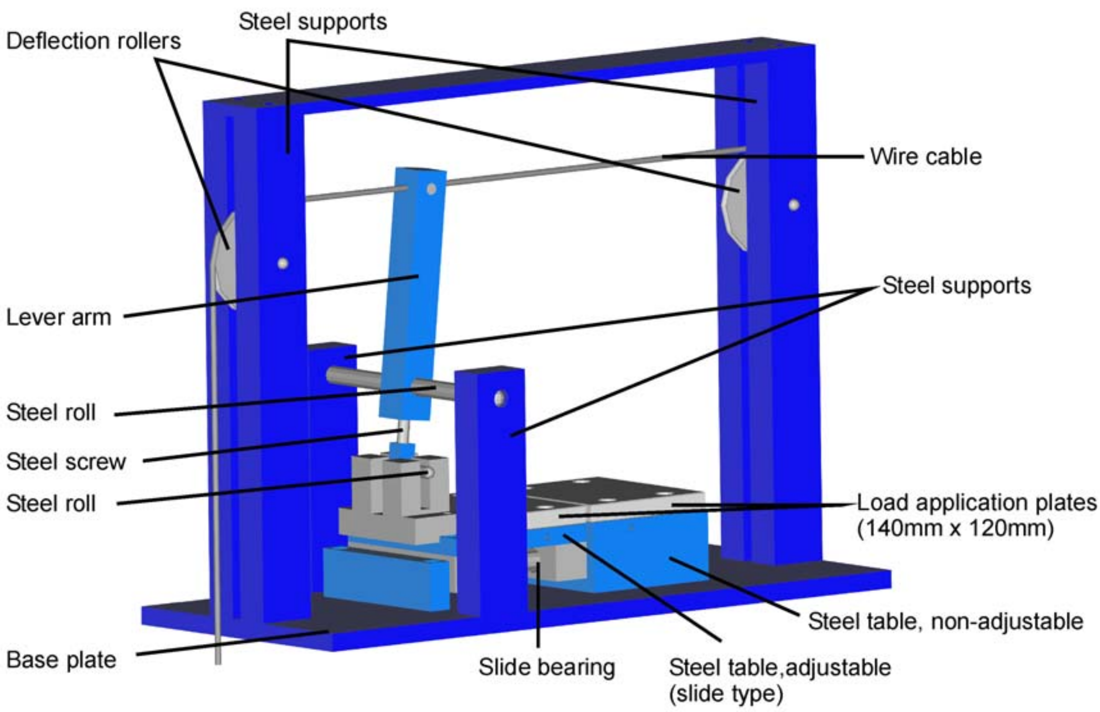

Figure 3 Schematic test set-up

It is possible by means of the new programmed software, with test set-up developed, to test the tensile force-deformation curves, the creep behaviour and the relaxation behaviour of rendering repair and maintenance systems in the applied state.
Moreover by presenting any time-dependent crack opening widths the deformation behaviour can be tested both under short-term and under long-term stress respectively with constant or cyclical load application.

Figure 4 Test state

3 Testing Program

In the carried out Research Project the following 4 systems, used in building practice for the repair and maintenance of renderings, were tested which differ basically in their coating design, composition and/or their mechanical properties:

- fibre-reinforced lightweight rendering (System A);
- textile glass-fibre reinforcement fabric with mineral, organically modified reinforcement rendering (System B);
- organic rendering with a coating thickness around 500 µm (System C);
- a paint coating system (System D).

Of the various systems the tensile force deformation behaviour under short-term stress, the relaxation behaviour and the crack bridging capacity in the applied state were determined with the new test method developed. The important stress for the case of application of a change in crack width was simulated by constant slow crack widening, taking into account relaxation influences (crack bridging capacity). A cyclical stress application, which was able to allow for an adequate relaxation time, could not be carried out owing to limitation time of the Research Project. Whether a relationship exists between the creep behaviour easily determinable by test and the relaxation behaviour, was checked in several comparative tests.
For checking the influence of the ageing process on the long-term efficiency of the rendering repair systems, the above mechanical properties of the system were also determined after artificial (accelerated) weathering and natural weathering. The reference test specimens were stored up to the day of testing at constant normal climatic conditions 20 degrees celsius and 65 percent relative humidity in the same climatic range in which they were produced. The artificial weathering of the specimens was performed in a climatic chamber. The weathering stresses corresponded to DIN

EN ISO 4892-3; with permanent UV radiation intervals of 1-hour moisture phases every 5 hours for a time of 2 months. The natural weathering of the specimens was carried out for about 6 months on the site of the Institute of Building Materials Research, Aachen.

4 Test results

4.1 General

After the artificial weathering the test specimens of Test Series A and B displayed a significantly changed surface structure. In the case of repair and maintenance System A the aggregate grains of the plaster could be clearly identified, in that of Test Series B the inlaid textile glass-fibre reinforcement at a number of places. Presumably the spraying of the test specimens resulted in washing out of the binding matrix. The test specimens of Test Series C had yellowish colour patches on the surface. The test specimens which were naturally weathered displayed a similar but not so marked appearance. On the naturally weathered test specimens at first only the tensile force -deformation was determined. As no essential differences were apparent between the non-weathered or the artificially weathered test specimens, further tests have not been carried out. The test specimens at present continue to be stored on the site of the Institute. The tests will be continued at a later date, if an effect of the natural weathering on the mechanical properties of the systems can be assumed. The System D was entered in the test programme at a later date. The test specimens could no longer be exposed to artificial or natural weathering prior to the test owing to the time limitation of the Research Project. Table 1 contains the main test results.

Table 1 Test Results (mean values)

System (thickness)	storage	Tensile		Creep		Relaxation		Crack Bridging	
		F_t [N]	Δw_{max} [µm]	φ_{1h} [-]	φ_{∞} [-]	ψ_{1h} [-]	ψ_{∞} [-]	F_{max} [N]	Δw_{crack} [2] [µm]
A (16 mm)	20/65	340	11	0,14	0,41	0,12	0,17	300	>14..50
	artificial weathering	420	36			0,24[1]	0,35[1]	400	>29..32
	natural weathering	490	23						
B (3 mm)	20/65	2230	1090	0,57 [1]	1,27 [1]	0,32	0,45	1620	≤260..400
	artificial weathering	2360	940			0,30[1]	0,40[1]	1860	<500[1]
	natural weathering	>2910	>1370						
C (0,6 mm)	20/65	280	31			0,41	0,51	160	>47..100
	artificial weathering	410	34	0,54[1]	1,41[1]	0,29	0,39	210	>50..120
	natural weathering	400	46[1]						
D (0,5 mm)	20/65	42	1700	1,34[1]	1,89[1]	0,73	0,84	18	1250..1390

1) single value
2) range of test results

In the *Tensile* tests (short-term) the maximum tensile force F_t and maximum change in crack width Δw_{max} were measured by increasing stress up to fracture in 1 to 5 min.
The *Creep* behaviour was determined by measuring the crack changing width while constant stress (1/3 of F_t in tensile tests). The creep coefficient φ_{1h} (t = 1h) and the calculated creep coefficient φ_∞ (t = ∞) are given in table 1.
To determine the *Relaxation* behaviour the changing in crack width w_0 due to an applied force F_0 (1/3 of F_t in tensile tests) was kept constant. The time dependent decreasing of the force (e.g. in Fig. 5) was measured. The relaxation coefficient ψ_{1h} (t = 1h) and the calculated relaxation coefficient ψ_∞ (t = ∞) are given in table 1
($\psi(t) = 1 - (F(t) / F_0)$).

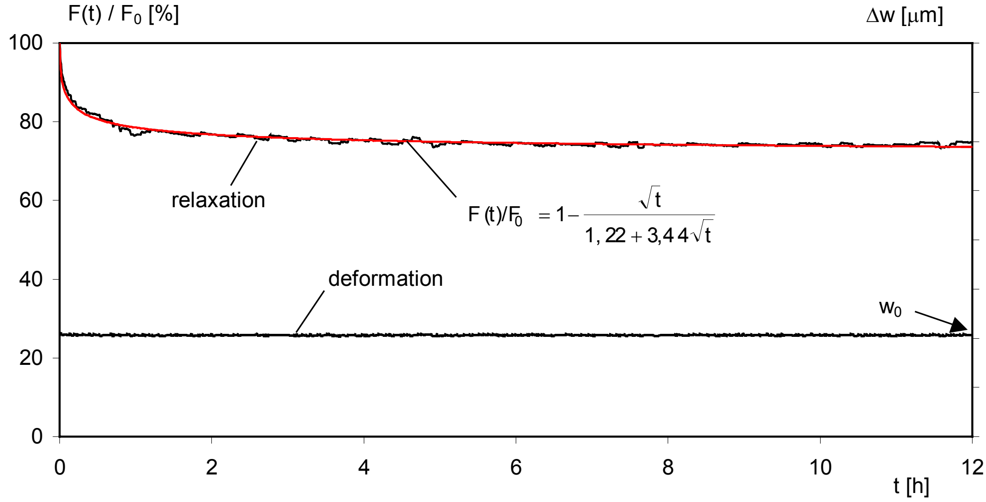

Figure 5 Relaxation curve: decreasing force $F(t)/F_0$ while constant deformation (crack width changing Δw) in dependence on time t, example (System C)

The *Crack Bridging* was determined by slow crack widening (up to 48 h) while deformations and forces were measured. Figure 6 shows a force - deformation curve of system C compared with a tensile test (short-term). The visible crack initiation Δw_{crack} at the surface of the system was evaluated by eye and is given in table 1, as well as the maximum force F_{max}.

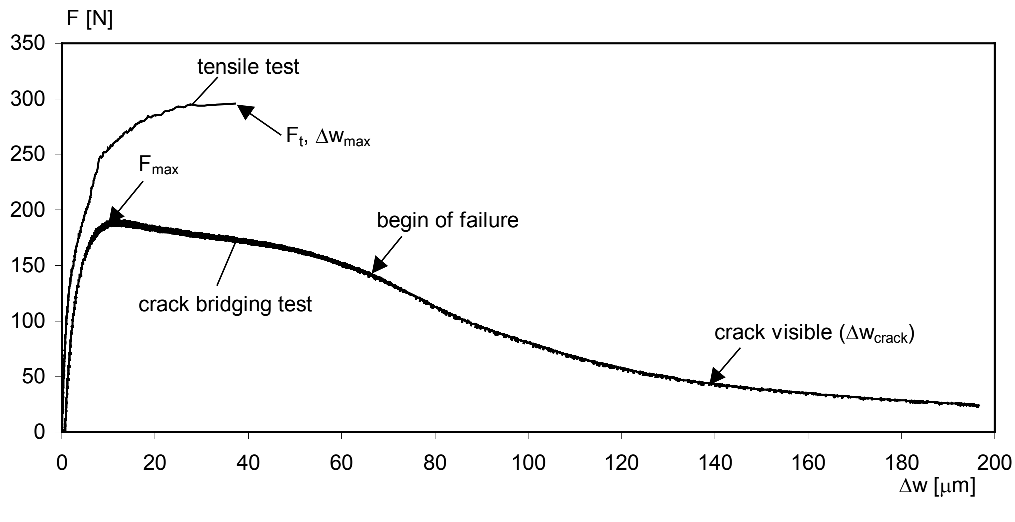

Figure 6 Force F – deformation (crack width changing Δw) curve of a crack bridging test and a short-term tensile test, example (System C)

4.2 System A

The artificial and natural weathering with test specimens of System A in the tensile tests led to higher loads at fracture and higher deformations at fracture and a higher reduction of stress in the relaxation tests. This behaviour was to be attributed to a lower bond of the weathered test specimens and hence to a detachment of the system on the crack sides. In principle the detachment of the coating of the crack sides has a favourable effect on the deformation properties. To what extent the low bond in practice however leads to a complete loss of the bonding capacity and to shell formation, cannot be evaluated on the basis of these test results. The differences in the material properties between the weathered and non-weathered test specimens were also apparent in the crack bridging tests, by higher maximum loads and greater crack width changes on reaching the maximum load in the case of the weathered test specimens. This applies similarly also to the relaxation tests. According to visual assessment there were no differences between weathered and non-weathered test specimens in regard to the point of time at which the first cracking could be identified in the coating. The advancing crack formation – increasing load decline in the crack bridging tests – takes place in the ranges of 10 to 20 µm. Crack widths on this scale cannot be identified in textured surfaces.

4.3 System B

For the test specimens of System B up to a slight increase in the stiffness and strength with natural weathering no appreciable influences of the weathering could be observed on the mechanical properties. With this system considerable cracks formed in the tensile tests and the crack bridging tests already before reaching the maximum load. An evaluation of this system is at present only possible by eye. The authoritativeness is therefore very limited.

4.4 System C

With System C brittleness was observed due to weathering stress. This is apparent both in the tensile tests and also in the relaxation tests. In the same way as the Test Series A, the force-deformation processes occurring in the crack bridging tests can be explained at least qualitatively with the results of the tensile and relaxation tests. The increasing decline in load in the crack bridging tests can be regarded as a failure criterion - with a further change in crack width, cracks may be expected.

4.5 System D

With System D the influence was clearly apparent of the rate of loading on the mechanical properties of the system and their effect on the evaluation of efficiency. In the short-term tests significantly higher rupture deformation cases were determined, than in the crack bridging tests. With the application of the high relaxation and allowance for the high deformations at fracture in the short-term tests the crack bridging properties of this system would have been overrated. The increasing decline in load in the crack bridging tests is in very good agreement with the failure observed in the coating and may also be regarded as a failure criterion for this system. The favourable relaxation behaviour of this system is in accordance with the highly marked horizontal course taken by the force-deformation curves.

4.6 Conclusions

In the tests on the crack bridging capacity the increasing load decline in the force-deformation curves may be regarded as a criterion for failure and the beginning of crack formation for systems *without reinforcement fabric*. In the optical assessment of the specimens before the increasing load decline of the force-deformation lines no cracks were to be identified in the coatings in systems without reinforcement fabric. The influence of the relaxation and the deformation capacity of the system was

apparent in the path taken by the curves after reaching the maximum load. In systems with high relaxation values (non-weathered test specimens of Systems C and D) a highly marked horizontal curve path was found. In System A and the weathered specimens of System C a steeper decline in the curves occurred. It is to be noted however that the testing rate also has a considerable influence on the specific characteristic values. The loading rate should be so selected that an adequate relaxation time is ensured, however the “deformation rates” occurring in building practice should be kept as the minimum and not fallen below, in order not to overrate the efficiency of the systems. An essential part of the stresses is normally reduced after 1 to 12 hours. The time-dependent characteristic values changed in the creep tests more slowly than in the relaxation tests.
In the systems *with reinforcement fabric,* in the crack bridging tests the above criterion cannot be regarded as a failure criterion, as definite cracks can already be identified before reaching the maximum load, which should also be classified as damaging in building practice (crack width > 0.2 mm).
The evaluation of the cause of the cracks – particularly in System B – is at present still according to optical assessment. On the one hand this is a subjective procedure, especially in tests with relatively low deformations, on the other, owing to the very long test times in some cases the actual point of the initial cracking occurring, cannot normally be exactly determined. A need therefore exists for an objective method for the determination of the quantitative point of time of the initial cracking in the coating or of the change in the crack width in the basic test specimen. Possibly, this aim can be reached by video measurement.

5 Summary

Within the scope of a Research Project carried out at the Institute of Building Materials Research Aachen (ibac) the tensile-deformation, creep, or relaxation behaviour and also the crack bridging capacity of the repair and maintenance systems were tested in the applied state without weathering, after artificial weathering and after natural weathering with a recently developed test method on different rendering repair and maintenance systems. The important stress of a crack width change for the case of application, taking into account relaxation influences (crack bridging capacity) was simulated by a constant, slow crack widening and compared with tensile tests (short-term stressing), relaxation and creep tests. A cyclical stress application, which allows for an adequate relaxation time, is possible with the test method developed, but could not be carried out however owing to the time limitation of the Research Project.
In the repair and maintenance systems without reinforcement fabric the thin-coat, organic Systems C and D are exceptionally deformable – particularly in the case of System D cases of high expansion at fracture and large relaxation figures were determined, which are in agreement with the high crack bridging capacity of the system. Weathering had the effect of increasing the brittleness of System C, the test specimens of System D were only tested without weathering. According to the state of knowledge hitherto the crack bridging properties of the thick-coat, mineral System A are less marked. Due to the weathering a detachment of the system from the crack sides was observed, which has a favourable effect on the deformation properties. The weathering of the repair and maintenance System B with reinforcement fabric has shown so far no appreciable influence on the mechanical properties. In contrast to the unreinforced systems according to initial crack formation definite increases in load are still possible. An evaluation of the crack bridging properties has not been possible so far for lack of a failure criterion.
In order to reach reliable conclusions on the efficiency of the plaster repair and maintenance systems, further tests – also under cyclical stressing – and the continuation of tests according to natural weathering are to be recommended.

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