

# CRACK WIDTH CONTROL IN RC BY ARAMID SKIN REINFORCEMENT

## RISSBREITENBESCHRÄNKUNG IM STAHLBETON DURCH ARAMID-HAUBBEWEHRUNG

## CONTRÔLE DE LA LARGEUR DES FISSURES EN BÉTON ARMÉ PAR RENFORCEMENT DE LA PEAU PAR ARAMIDE

Hans W. Reinhardt, Friedrich Paul

### SUMMARY

Tensile tests on concrete prisms with one central steel bar and three layers of aramid fabric are described. The results from prisms with and without aramid are compared and discussed with respect to numbers of cracks and crack width. The example shows the effectiveness of the aramid skin reinforcement.

### ZUSAMMENFASSUNG

Zugversuche an zentrisch bewehrten Betonprismen mit und ohne Aramidgewebe als Hautbewehrung werden beschrieben. Die Ergebnisse werden verglichen hinsichtlich Anzahl und Breite von Rissen. Es zeigt sich, daß die Aramid-Hautbewehrung einen sehr günstigen Effekt hat.

### RÉSUMÉ

Des essais de traction aux prismes du béton armé avec une barre centrale d'acier et trois couches du tissu d'aramide sont décrits. Les résultats sont comparés par rapport au nombre et à la largeur des fissures. On montre que le renforcement de la peau du béton par aramide est très efficace.

**KEYWORDS:** reinforced concrete, cracks, crack width control, aramid, skin reinforcement

## 1. MOTIVE

For durability reasons, crack width in a concrete structure should be controlled. The Eurocode 2 [1] limits crack width to 0.30 mm for external exposure and the German Standard to 0.15 mm for water retaining structures. A reduction to 0.10 mm is envisaged for structures which should retain other liquids than water. These requirements can be met if small diameters are used or the steel stress is reduced (e.g. 200 N/mm<sup>2</sup> for a 25 mm bar). A small cover would also reduce crack width. However, small cover and small bar diameter increase corrosion rate. In this area of conflict a compromise could be the use of large steel bar diameters and a skin reinforcement of corrosion resistant fabric, e.g. aramid.

## 2. MATERIALS

### 2.1 Aragrid

The aramid grid is a square woven net made of threads which are about 1 to 2 mm thick and consist of thin aramid filaments of 10  $\mu$ m diameter. To increase durability and to protect the filament against mechanical damage the threads are covered with protective plastic sizing. The strength and size of these fibres are similar to asbestos. However, they are not carcinogenic. Generally speaking, the strength of aramid exceeds high strength steel. The ultimate strain is between 2 and 5 %, the density around 1.45 g/cm<sup>3</sup>. Young's modulus ranges between 40 and 150 GPa.

Aramid is not affected by carbonated concrete or chlorides. Longtime exposure in pH 4 to 8 will result in 20 % strength loss. Although UV light hurts aramid this is not a problem if it is embedded in concrete.

Aragrid is a product of Enka and is delivered in two types: small mesh and large mesh. The difference is the spacing of the threads with 10 or 13 mm, respectively. The fabric is delivered in long sheets about 1 m wide. Specimens can be cut easily by using a scissor.

Bare samples of the fabric were tested in direct tension in both directions: in warp and weft direction. Since the number of threads per unit length is not exactly the same in both directions it is preferred to use the carrying capacity of a thread as a practical strength parameter instead of the strength per cross-section.

The pilot series showed a carrying capacity of 0.618 kN per thread. A second series resulted in 0.779 kN per thread (coeff. of variation: 5.2 %). The ultimate strain was found to be 1.5 to 2.3 %. Young's modulus cannot be determined accurately since the cross-section is not exactly known. A rough evaluation led to 30 to 70 GPa.

## 2.2 Concrete

The composition of concrete is given in Table 1. The strength properties have been determined on 150 mm cubes at 28 days.

Table 1. Concrete composition, per m<sup>3</sup>, and standard properties at 28 days

Portland Cement (PZ 35 F)	305 kg
Quartzitic aggregate 0-16 mm	1858 kg
- fraction 0-2 mm	35 %
- fraction 2-8 mm	35 %
- fraction 8-16 mm	30 %
Water	177 kg
Water/cement ratio	0.58
Cube compressive strength	44.5 MPa
Splitting strength	4.9 MPa

The fresh concrete had a density of 2340 kg/m<sup>3</sup> with an air content of 2.2 %.

### 2.3 Steel

The steel bar was a deformed reinforcing steel with a yield strength of 500 MPa (acc. to DIN 488, but 610 MPa from actual testing).

## 3. TESTING SPECIMENS

The specimen is a prism 655 x 150 x 150 mm with a central reinforcing bar  $\phi$  28 mm and three layers of aramid fabric on two opposite sides. Fig. 1 shows a view and a cross-section of the specimen. During fabrication, the fabric layers were positioned at the lower and upper side of the mould and were stressed a little in order to keep them in place. First a 8 mm cover layer of mortar with 5 mm max. aggregate size was poured, then the concrete was filled, the upper layers of fabric were mounted, and finally the upper cover was poured.

Reference specimens were made without fabric layers, but with the same concrete and steel bar.

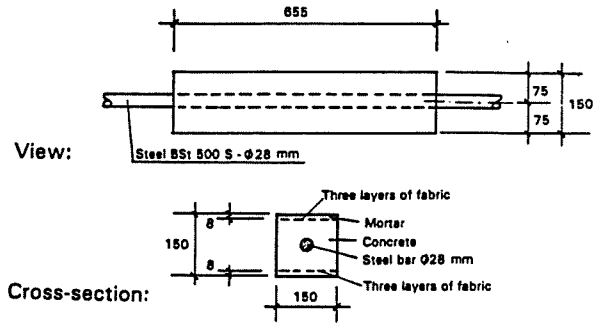


Fig. 1 Specimen with central steel bar and two times three layers of aramid fabric (in mm)

#### 4. TESTING PROCEDURE

The steel bar was clamped in the grips of the testing machine. LVDTs were mounted to the concrete (measuring length 510 mm) and to the steel (length 720 mm) which measured the total elongation of concrete and steel, respectively. The load was applied in steps of 50 kN and cracks were monitored. The crack width was measured optically with a microscope.

When the load reached a certain value a longitudinal splitting crack appeared at both ends of the prism. This was due to the bond forces of the steel bar and the confining action of the fabric which acts excentrically to the steel force. In

order to avoid splitting a steel collar was put on both ends of the specimen to confine lateral displacements. By that, splitting cracks were avoided.

## 5. TEST RESULTS

Since the main idea was to control crack width only cracking data will be reported. Cracks were measured on four sides of the prism, two of them with skin reinforcement and two without. The difference between the two pairs should indicate the effectiveness of a skin reinforcement. Since it was not known in advance whether the fabric could also affect the behaviour of the two sides without fabric reference specimens without fabric were tested and measured in the same way.

Test results are presented in Figs. 2 to 4 and in Table 2. The number of cracks of all individual specimens are given in Table 2 together with the mean value of the series. The numbers increase with the load as expected. Fig. 2 contains the crack width vs. steel stress.

Table 2. Number of cracks in all specimens tested

Load kN	Specimen sides with fabric					Specimen sides without fabric					Concrete specimens				
	5	6	7	8	x	5	6	7	8	$\bar{x}$	2	3	4	5	$\bar{x}$
50	1	1	1	1	1	0.5	1	1	0.5	0.8	1	1	1	1	1
100	2	1	1.5	1	1.4	1	1	2	1	1.2	1	2	1	1	1.2
150	2.5	2.5	2	3	2.5	2	3	2	2.5	2.4	1	2	1.7	1.3	1.5
200	3.5	3	3	3.5	3.2	2.5	3	2.5	2.5	2.6	2	2	2	1.5	1.9
250	3.5	4	4.5	3.5	3.9	3	4	4	3	3.5	2	2	2.2	2.5	2.2
300	3.5	5	4.5	4.5	4.4	3	4.5	4	3	3.6	2	2.3	3	2.8	2.5
350	4	5.5	4.5	5	4.8	3.5	5	4.5	3	4.0	2.7	2.3	3.2	4.2	3.1
400	5.5	7	7.5	7	6.8	5	6.5	8.5	7	6.8	5.3	5.7	5	6	5.5

Remark: Since the numbers are mean values of two or four sides they may be not integers.

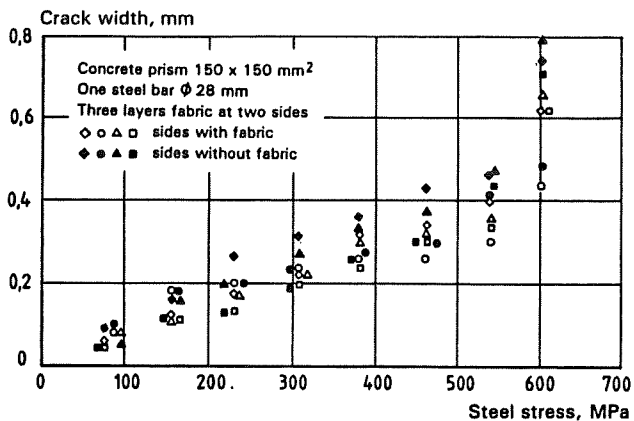


Fig. 2 Crack width (mean of max. values) vs. steel stress of concrete prism with fabric

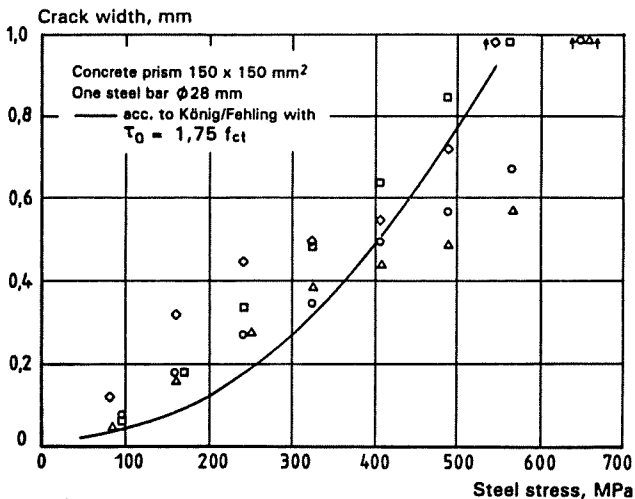


Fig. 3 Crack width (mean of max. values) vs. steel stress of concrete prism without fabric

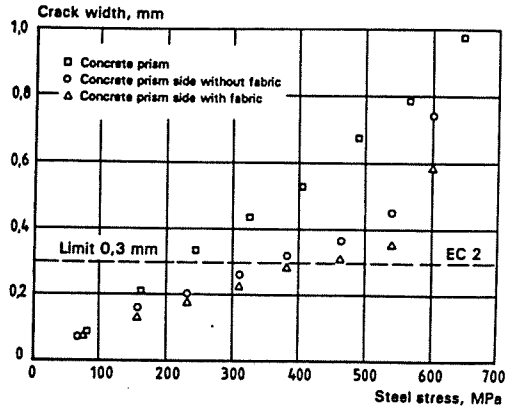


Fig. 4 Crack width (mean of all max. values) vs. steel stress

The crack width is calculated as mean of the maximum values at two sides of the specimen, one with fabric (open symbols), one without fabric (black symbols). The steel stress is calculated from

$$\sigma_s = \frac{F_{tot} - F_{fab}}{A_s} = \frac{F_{tot} - E_{fab} A_{fab} \Delta l_c / l_m}{A_s} \quad (1)$$

with  $F_{tot}$  = total load,  $E_{fab}$  = Young's modulus of fabric,  $A_{fab}$  = cross-section of fabric,  $l_m$  = measuring length on concrete,  $\Delta l_c$  = elongation of concrete with cracks included,  $A_s$  = cross-section of steel bar.

Fig. 3 shows the results of the reference specimens without fabric. Finally, a comparison of the test series is made in Fig. 4 using mean values of the three series. The limit according to EC2 is indicated.

## 6. DISCUSSION OF THE RESULTS

### 6.1 Number of cracks

The mean values of Table 2 indicate that most cracks develop at the specimen sides with fabric. This is due to the reinforcing action of the fabric which introduces forces into the concrete between the cracks and yield another crack. The difference between the sides with and without fabric is consistent but small. It must be concluded that the fabric has affected all four sides of the prism. The difference to the specimen without fabric is clear especially at load steps of 150 kN and more. This behaviour confirms that a fabric skin reinforcement is effective and causes a narrower crack pattern than without fabric.

### 6.2 Crack width

Crack width is directly correlated with the number of cracks. At the same elongation, more cracks mean less crack width. Fig. 2 shows that the crack width is smaller on the sides with fabric than at the opposite ones. However, the differences are rather small although they are consistent. A rigorous statistical treatment of the data, especially up to a steel stress of 500 MPa, would not show a significant difference.

The crack width of the prisms without fabric as shown in Fig. 3 shows larger values than in Fig. 2 and a greater scatter. The solid line is calculated with a rigid plastic model for bond [2] with a bond strength equal to 1.75 times axial tensile strength of concrete ( $= 0.9$  times splitting strength). It can be seen that

the model underestimates the experimental data up to 0.4 mm while larger values are well predicted.

A comparison of the three test series is made in Fig. 4 which shows clearly the beneficial influence of a fabric skin reinforcement on the crack width. A steel stress of 200 MPa causes a crack width 0.26 mm for the concrete prism and 0.15 for the skin reinforced prism, a stress of 400 MPa leads to 0.55 and 0.28 mm respectively. The Eurocode limit is reached at 220 MPa by the concrete prism and at 420 MPa by the other. This means almost doubling the allowable stress for the same crack width.

## 7. CONCLUSION AND SUGGESTION

The tests on fabric reinforced skin concrete have clearly shown that crack width is significantly reduced. If, for durability reasons, crack width is limited a skin reinforcement would allow much higher steel stresses. Practical examples are suggested to demonstrate the economic effect of such a measure. Detailing of the fabric skin reinforcement, e.g. cross-section, anchorage, splices, and long term performance, e.g. creep, relaxation, should be investigated in the future.

## 8. REFERENCES

- [1] Eurocode No. 2. Design of concrete structures. 1991
- [2] König, G., Fehling, E. Zur Rissbreitenbeschränkung im Stahlbetonbau. Beton- und Stahlbetonbau 83 (1988), No. 6, pp 161-167, No. 7, 199-204