SMAR 2015 – Third Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

Coming European Standard for R/C Design EC2 - Integration of FRP rebars

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ABSTRACT: In the last decades in several markets different guidelines for the design of R/C structures have been set up. In addition in some European countries like Germany and the Netherlands national approvals have been worked out for these materials.

The extended knowledge and the design safety is a basic prerequisite for the use of FRP, while the growing use of FRP is an accelerator for the European standardization process. The author is member of different committees and task groups and reports on new and partly unpublished developments especially of the new EC2 groups.

1 INTRODUCTION

If In most countries construction work and building materials are regulated due to the common understanding of public safety. Therefore building material as well as the design is defined or enough experience shall be available in a traditional way of construction. For new materials like FRP the latter is generally not the case, so there is a need for a regulation.

There are three common ways to regulate a building product:

The first way is the standard (national or international), where properties and/or the design for this product is defined.

In the second way is the approval for a special building product, where no standards yet have been established. This possibility is defined with a limited application range or limited properties or geometry or manufacturing of a special product.

The third way is a one time certification, where a special material or a special way to construct is not yet approved or differs from the regulations in a standard or an approval.

For all three ways there shall be the same safety level. This safety level is defined through the failure probability. It is possible to have a different set of safety factors but the same failure probability. The acceptable safety levels and the actions on the structures are defined in the basic European construction standards EN1990 and EN1991. The fundamental condition in design is that Resistance of the structure is greater than actions (load) on the structure. Both actions as well as resistances are described by a certain defined probability. To simplify the description characteristic values are introduced. In a semi-probabilistic frame the following figure can be drawn. [1,2,3]

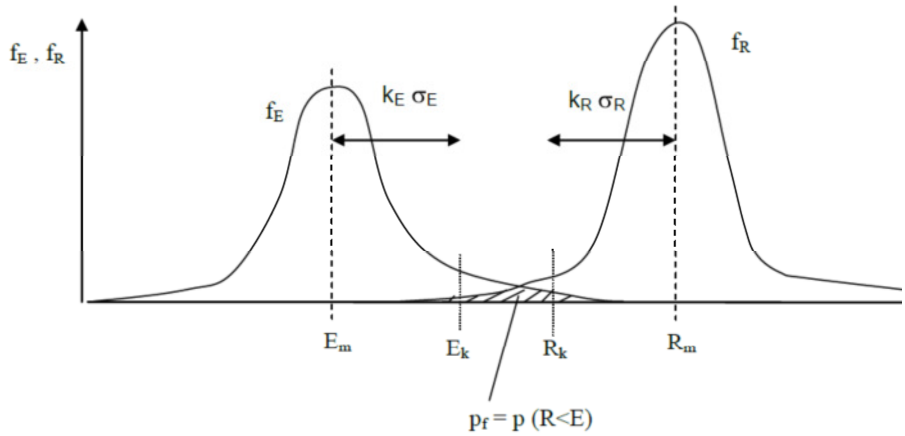

Figure 1: Probabilities of the action E and resistance R

It has to be stated that there is always a certain probability of a failure. The probability can be influenced by the introduction of safety factors for the design and the definition of characteristic values.

For a typical reinforcement steel BST 500 the characteristic yielding strength fyk is 500MPa. As the distribution of the yield strength is very narrow, a material factor of 1.15 is introduced. With this material factor the design strength fyd is determined to 500MPa/1.15 = 435MPa.

On the action side of the equation different factors for live load and dead load or accidental load apply. These are functions of the probability and are defined in the basic Eurocode documents.

For FRPs and a short term design this seems similar, but for all long term applications we have to integrate the time dependent properties like strength and bond strength in the basic equations. In contrast to material specific guidelines like ACI 440 or CSA S806/S807, the EC2 group did not want to look to deep into material specific specialties. The need was a save and dependable as well an economic design. The solution for this apparently contradictory needs was the definition of save and dependable long term values for the design, which are not derived from short term values by the engineer, but from long term tests defined by (European) technical approvals. The next paragraphs show different possibilities.

2.1 Concept ACI 440.1

In the guideline all design values are derived from short term strength values. The engineer has to decide if the application is long term or short term and if the environmental conditions are wet or dry. In conjunction with the material class (carbon, aramid or glass) an environmental factor can be determined.

Testing shall be performed at 0.2% strain in an artificial pore solution.

The design limit is 20% for sustained loads compared to the guaranteed (characteristic) tensile strength. Including the environmental factor this is reduced to 14-16% [4,5]

In ACI there seems to be no relation between testing and later load. Both regulations (testing limit and design limit) are experience based and have no probabilistic background.

The limit for testing is based on the experience for most secondary and crack distributing applications made in the last decades. While the limit for the sustained load is based on Japanese creep rupture tests in the nineties [6]. The basic approach is that in typical strains of the application there is no or only minor stress degradation. Therefore limits are defined.

For a typical FRP rebar with a rupture strain between 1,5 and 2% this seems to be not evident for the author, why a bar should be tested with a strain of 0.2% and a maximum strain between 0.3% and 0.4% shall be allowed in serviceability state.

2.2 Concept CSA S806-11

In the recently revised Canadian code the durability testing shall be performed at 0.3% strain. While the limit of 0.2% strain for sustained loads shall be considered [7,8].

This seems to be much more evident. But as there are fixed values and no statistic evaluation on these parameters this is not fulfilling the semi-probabilistic approach.

In addition a question is raised how the live loads are handled in this approach and what are the real limits for the tested materials. This question is covered in the European approvals and coming codes.

2.3 Safety concept in Europe

For FRP rebars in Europe there are now national approvals in two different countries [9,10]. In these two approvals the basic properties are handled as following:

The maximum sustainable stress for 100 years and 40°C is determined and a characteristic value is calculated. For this value a material factor is introduced and a design value can be determined. In the following figure the resistances and the actions including their probabilities are depicted:

It is clearly to be seen in figure 2 that along the line in the range of 5000 to 10000h at 60°C the same safety system applies as for a not time dependent material.

What also can be determined out of the diagram that for this material a testing at 60°C for a time range up to 10000h is comparable to a testing at 40°C and a regression analysis with a forecast to 100a at 40°C. By shifting the vertical line to 100a and using the 40°C line, the same safety applies.

A European standardization for the material has not yet been started and seems to be not useful as there are still new developments, which can make it impossible to standardize these materials. So the European commission and the European Organization for Technical Approvals EOTA have discussed this issue and the following solution has been fixed:

The material properties shall be defined by European Technical Approvals, while the design shall be regulated in standards. Therefore the CEN has called the TC250 WG for the design task.

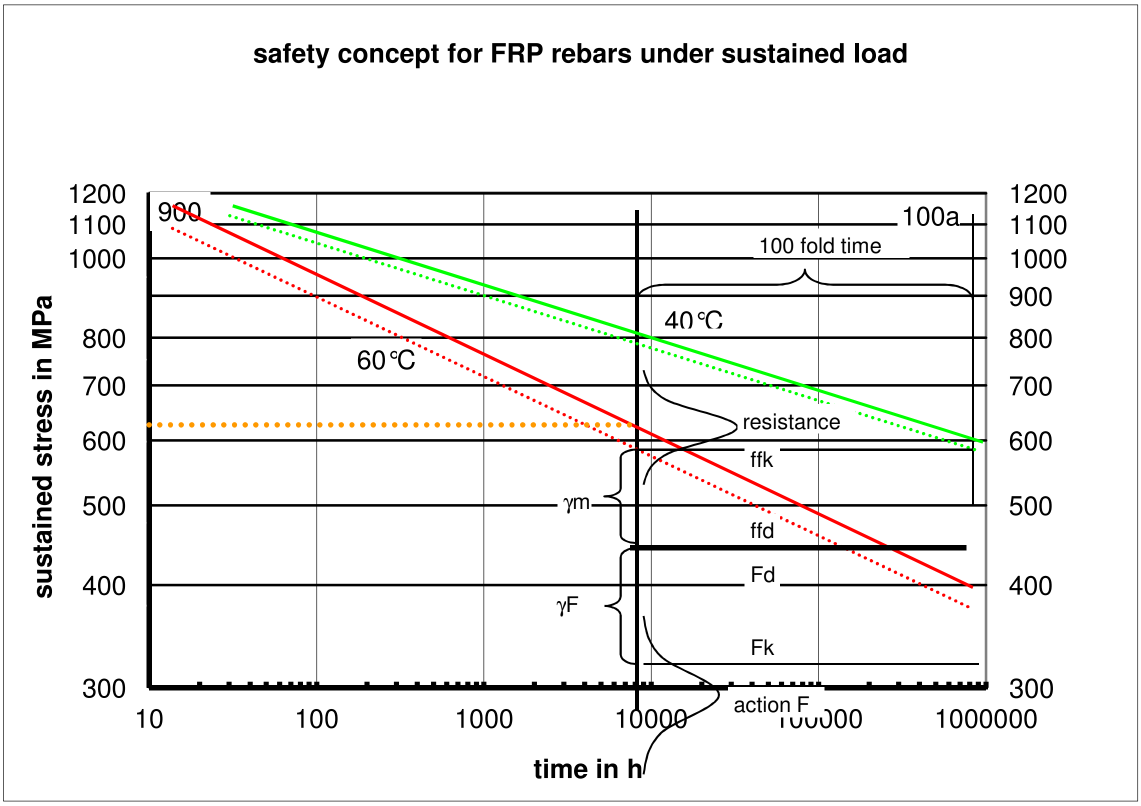

Figure 2: Safety relations for time dependent FRP rebars under load

The process for the European Technical Approval (ETA) is defined in the Construction Products Regulation (EU) No 305/2011 (CPR) [11] . National building authorities can organize this certification process. For this building product Germany has the mandate for the determination of the assessment document, which defines the testing rules and the possible range of properties.

With this connection between European approvals and European design standards it is important which properties are defined in the approval and which properties are needed for the design. As for all FRP materials the properties are time dependent, there is a general accordance, that long term properties shall be used for the design. Which are these time dependent properties?

For the basic design of a reinforcement material the strength of the material itself and the anchoring of the material are the most important properties.

3. DETERMINATION OF LONG TERM VALUES

Is it possible to generate a long term factor and to determine the long term values from short term values? Which conditions shall be defined for the application? In EN 1991 a maximum long term temperature of the structure of 37°C is defined. For shorter periods temperatures can be as high as 65°C in special structures like facades or balconies.

So the assumption for the worst conditions for the whole service life is 40°C in connection with high alkaline moist concrete.

The interesting question is now which load can be sustained for a typical service life of 100 years under these conditions.

This combination of exposure conditions simplifies the long term testing, as in reality there is also always a combination of tensile stress, alkaline exposure, humidity and temperature. The way to get the most accurate and the most economic results is to keep the tests as close as possible to reality and to combine the main influences as in reality.

3.1 Long term material behaviour

The most important point is that for any composites, it is not possible to determine long term properties from short term properties. If we change only on parameter (for example the diameter) the calculation gets wrong.

We have to look deeper into the material, to understand how a material which is made of thousands of fibres and a resin which glues these fibres together behaves[12]. In long term tests there is a limited possibility of equilibrium actions and we have to look what happens there. In figure 3 we see a creep test of a material under high loads.

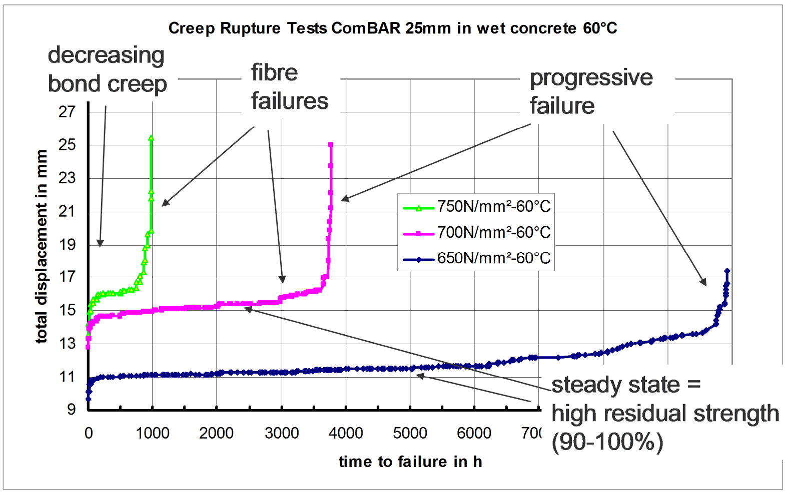

Figure 3: Creep with different incidents

There is a certain probability of a fibre failure depending on local stress temperature and time. A small failure can be balanced by the neighbour fibres within some millimeters. But the load for these fibres is slightly higher and the failure probability also. As long as this is in a steady state the strength of the bar will not change. Only at the beginning of the progressive failure the strength will decrease.

If we would test the bar with 650MPa on residual strength at the time of 5000h we would see a strength not far from the virgin strength. The bar is intact and the creep is in steady state. The bar at 700 MPa is already broken. So only some percent more load will generate a failure. There is no possibility of an extrapolation of the residual strength because the creep gets nonlinear at the end.

There is not even the possibility to test if the bar is still ok. The only way is to design against the failure points by the creep rupture method.

3.2 Can we use environmental factors like Ce?

For example a rebar of the diameter 16mm has a virgin strength of 1200MPa the characteristic strength for 100a exposure at 40°C is 580MPa. What will be the characteristic strength of a 8mm and which will be the one of a 25mm rebar. The 8mm has a short term strength of 1600 MPa and the 25mm a short term strength of 1100MPa. To solve this confusion we have tested the durability with rebars of different diameters but same material.

The creep rupture tests in wet concrete at 60°C have shown, that there is no diameter influence in long term exposure as can be seen in the following figure despite there are different short term strengths. So it could be shown that even for one material there is no unique factor to determine long term strength from short term strength.

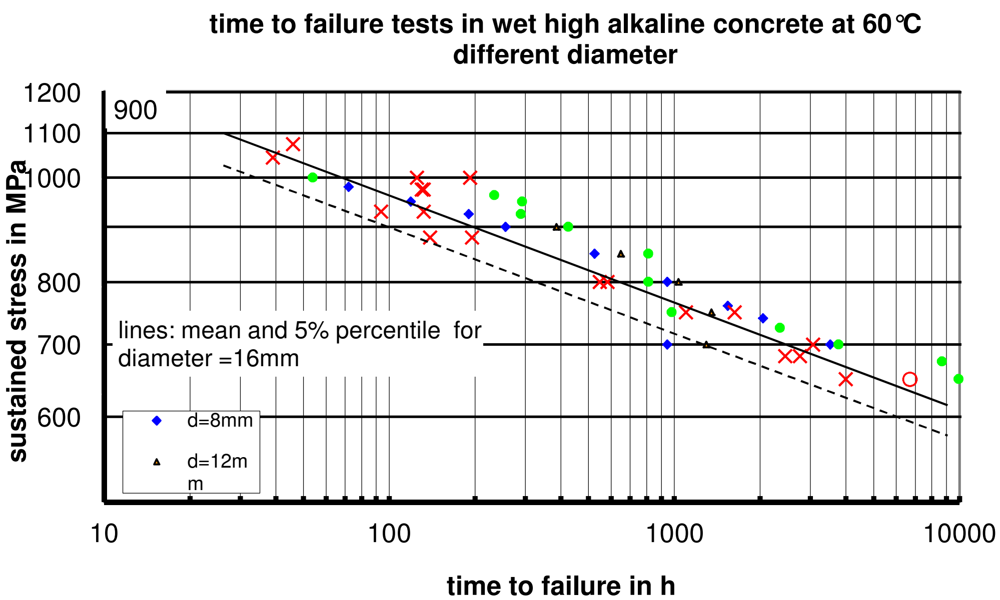

Figure 4: Creep rupture tests with different diameters

To define a reduction factor anyhow like done in the ACI440 or the Canadian CSA S806 should be done with great diligence only very conservative if done on a general base. At the time the first drafts for the ACI 440 have been written, values between 30 and 57% of the virgin strength are known from creep rupture tests. The ACI committee has taken a limit of 20% to introduce a safety factor of 1.5, while the Japanese JSCE code has drawn the conclusion, that glass fibre rebars and tendons shall not go into structural applications.

In Europe performance based approvals are wanted, to push better materials and new developments. In so far approvals with fixed limits or fixed percentages will not be promoted.

4. PREVIEW TO THE DRAFT STANDARD

The coming standard is developed by different project groups. The author is national member of the FRP reinforcement group. Other groups dealing with fire resistance, shear or steel fibre work on the same standard. The compilation is done afterwards by the main group.

The work in the internal reinforcement group is organized by checking every sentence and every clause according the following criteria.

- Could be taken unchanged.

- Had to be changed in the wording (reinforcment steel is replaced by reinforcement)

- Had to be adjusted by a simple stiffness or stress relation

- Different approach had to be taken

- No approach yet known or accepted.

There was a list of more than 100 clauses. And only a small percentage had to be changed.

The following points were the biggest changes:

Partial factors have been defined

A one page material section for FRP has been introduced

Shear without shear reinforcement

Shear with shear reinforcement

Serviceability limits for cracking

Mandrel diameters

Some limits in the anchoring

In the coming new version of the EC2 internal rebars will be integrated in the main text.

So different rebars of different material properties like steel (normal and stainless) in different quality steps as well as the different FRP rebars of different fibre materials will be handled parallel to each other in the design of concrete structures.

The design of external bonded reinforcement and near surface mounted materials will be defined in a special section of the new EC2.

It has to be pointed out that the basic bending formulas do not change at all. As basic physics like momentum and force equilibrium is valid for FRP materials also only taking into account the different stress strain law of the material. In contrast to material specific guidelines like the ACI 440 there is no definition of a preferred reinforcement ratio. Under-reinforcement as well as over-reinforcement is allowed assuming save long term properties as well as save partial factors.

5. CONCLUSIONS

International guidelines like ACI440.1 and CSA S806 are mostly experience based and do not provide a semi probabilistic safety concept. The failure of a bar is an ultimate limit state and shall be tested in an adequate manner. Good behavior at serviceability limit state also in long term tests (like low creep or high residual strength) will not give any information on the behavior at higher loads. It is basically important to define test standards which define not only the result but also the evaluation of the result.

Different ways to show the behavior at ultimate limit state are possible: Extrapolation of rupture points at 40°C, tests to failure up to a range of 5000-10000h duration at 60°C and tests at a load which can be sustained for this duration at 60°C can be taken to determine the 100a long term strength.

Important is to apply the right factors to the results of the tests. Generally the test loads are seen as mean loads. Out of these values the characteristic values and with the help of a material factor the design values can be calculated.

This all will be regulated in European Technical Approvals and in the near future the design can be performed by the coming new Eurocode 2. I invite all experts in this field to discuss the safety and design concept with a semi-probabilistic approach.

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