2nd International Workshop on GFRP Bars for Concrete Structures

"Advances in concrete reinforcement"

SUMMARY DOCUMENT OF DISCUSSED MAIN POINTS

January 18-19, 2019
Orlando Florida

1- Summarized/categorized bullet points

Education

- The more people trained on the benefits and how to design with FRP bars, the more likely they are to be used. The alternative to use FRP should be taught to students in college so that when they graduate, and become young designers, they have the necessary knowledge to identity when it is suitable to use FRP.
- A healthy industry-academia relationship has unparalleled, unequivocal benefits to both parties and to the society as a whole.
- The role of education and raising professional awareness in promoting the technology and removing the barriers between the manufacturers, consultants, and the end-users is fundamental.
- Teach the public about the strengths and advantages of the FRP materials: there is still a lack of knowledge among the designers and contractors, this may result in a constraint for the use of FRP. A good way is to highlight the savings in terms of cost at the beginning of the construction (the initial cost of FRP material is higher than steel but there are others savings that reduce the total cost thanks to their use) and not only after the life cycle, because the initial cost may be more important for a possible owner.
- Education for the contractor. Construction specifications in practical operation.
- Correlation between the real scale (manufactures, contractors, construction side, costs) and the results from academia. Providing an appropriate language for users to better persuade them to specify, more focused on contractors and customers. Explain in an easy way emphasizing the benefits of the material (also in terms of costs in a short-time period).
- Need to develop software to design FRP reinforced structures: maybe based on steel design software, which will facilitate the design taking into account the different existing standards (AASHTO, ACI, CSA…). This will provide a higher confidence and reliability to designers as well as contractors. For a design community.
- Having FRP as an alternative to steel reinforcement in design software like SAP, STAAD, or the Autodesk suit would change the perception that designers have of this material.
- Build the confidence of engineers in designing with FRP. provide design software for designing FRP reinforced structures and validate them.

Material properties/characterization

- Guaranteed limits related to the real application in construction? (It could be lower in some cases). Balance of DOT requirements and design perspective.
- Energy dissipation, of GFRP reinforced elements during earthquakes[1].
- Specifications have to show clearer definitions about the limitations that the manufacturers have to follow, in order to have better final products and not problems such as definition of lot or size of bars.
- Raising too much the performance threshold may render FRP non-economic. This may result from choosing resins of excessive quality. (comment from a resin manufacturer).

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[1] Many tests have shown that GFRP-RC has the capacity to deform substantially (load versus deflection) which provides the ability to absorb energy. Hence, the lack of ductility in GFRP does not necessarily directly translate to a brittleness member-system response.

Tests have shown that concrete columns reinforced with GFRP longitudinal bars and spirals and tested under simulated earthquake forces behaved in a robust manner displaying large amount of ductility and energy dissipation capacity. It is true that the use of GFRP longitudinal bars generally results in lower strength and stiffness of columns compared with steel bars. The overall strength and ductility of columns reinforced with steel longitudinal bars and confined with GFRP spirals was found to be similar to or better than that of columns confined with steel spirals. Confinement with steel in columns deteriorates rapidly after yielding of steel (0.2%, 2 000 microstrain), due to the reduction of modulus of elasticity of steel after yielding, while GFRP spirals are capable of providing effective confinement until a strain of about 2% (20 000 microstrain) thereby delaying crushing of the column core.

GFRP spirals can be used as an effective primary lateral reinforcement in concrete columns designed for non-seismic and seismic regions.

It is acknowledged moment redistribution through plastic-hinging of FRP-RC. members/connections is not possible with FRP-RC, but the reduced elastic stiffness of crack FRP-RC members may allow for some level of redistribution of forces within the structure to enhance energy dissipation. More investigation into this phenomenon for framed structures should be explored.

- Is Basalt better than glass? Even if it has better mechanical and durability performance, is the basalt fiber industry mature enough to guarantee adequate quality control?
- Need to further investigate the environmental factor C_E. Can we work with environmental tools available nowadays to engineers and researchers to better quantify the C_E factor and its impacts, similarly to how it has been started with the C_C (creep factor).
- Deflection does not appear to govern in Barrier-Walls, Crash-Walls, MSE-Walls, Precast Concrete Walls and other vertically oriented main structural elements, which will hopefully lead to more mainstream usage of GFRP and BFRP, among others and make these materials more known to the industry.
- Relative Standardization of bar diameters between different Manufacturers, similar to the steel industry. For example, a #5 bar should be within specified tolerances of a #5 bar, between different Manufacturers (the bar diameter should not be allowed to vary by 30% or 40%, etc.., for uniformity and standardization purposes). This will lead to more readily acceptance in the Construction Industry, since large variances are removed. The size range limits have now been addressed by ASTM D7957-17.
- Bar standardization – Bars should not be standardized to adopt the same manufacturing process, exterior surface, appearance, etc. but must comply with the strength requirements and other requirements by codes.
- Durability – More research is needed in the area of durability testing and correlation between the collected results and the field performance. 365 days in hot seawater simulates how many years in the field?
- Fatigue – Moving toward implementation of composite reinforcement in the building is not possible unless fatigue refinements are addressed.
- Repair: possibility to repair GFRP elements, also the problem to find GFRP bars inside an element.

Certification

- Facilitate manufactures to get certification/permits so they can sell products. Harmonization/co-validation of certificates? Are the requirements/conditions of some certificates reflecting the level of manufactures? (e.g., minimum tensile strength).
- The importance of test standards, acceptance criteria, codes and provisions in jump-starting the innovative materials in a rather traditional industry.

Cost

- Cost – In order to be competitive in the market, the pricing of composite reinforcement should be simplified. The potential savings in the construction and life cycle cost needs to be recorded for different applications (seawall, piles, pile caps, bridge substructure and superstructure, etc.) and compared with other types of reinforcement (black steel, galvanized and stainless steel, etc.). This will allow owners to make their decisions based on facts and numbers.
- Cost-efficiency must always be accounted for when developing new material systems.
- Relying on LCC is tricky. It is not appealing to contractors, and private owners may not be educated to appreciate the advantage or trust the analysis.

Quality Control

- The need to qualify bars for industry. Introduction of minimum QA/QC requirements (possibly by 3rd Party Inspectors or others that are designated). Require testing of Lots, etc. only once for qualification (Lots that make sense size wise) - global requirements, including USA Codes, Eurocodes, Canadian Codes and others. One time cost to Manufacturers, instead of multiple times.
- Recommended to develop a standardized yet "simple" short duration QA/QC Verification Test Method for GFRP and BFRP and other specialized material composites.
- QA/QC – Quality assurance and quality control must be in accordance with established standards but process should rely on the manufacture.
- Quality control: need to minimize the impacts given by long term tests, such as the moisture absorption[2]. The material behavior curve after 2 days flattens, can we assess the acceptance criteria accordingly? Can we find a way to just use the 2-day behavior, rather than testing up to 11 weeks?
- What should be considered as a lot?

[2] The new edition of CSA S807 requires only 24h and one week data as follows:

The QC and QA tests shall be conducted in accordance with procedure 7.1, Twenty-four hour immersion, of ASTM D570 except that a water temperature of 50 ºC shall be used for both straight and bent bars.

The specified limits are: <u>For 1 week immersion: </u>≤ 0.45% for all bar sizes

<u>For 24 hr immersion:</u>≤ 0.25% for bars of size 15 mm and larger; ≤ 0.30% for bars of size 13 mm and smaller

Absorption tests for long-term immersion (until full saturation) are not required for QC and QA tests

2- Notes

(Digitalized notes directly taken from the notepads used during the open discussion. Categorized)

Market/Cost/$

- What are the top 3 priorities the FRP manufacturers need to work on to satisfy the needs of end users?
- Collective marketing of FRP Industry i.e. better collaboration among participants/members
- First cost comparison between stainless & FRP
- Unavailable US raw supply
- Are we now considered cost effective? First cost, life cycle cost
- Time to market delays due to: certifications, field tests and research in progress
- After Florida, what are the next 3 states to adopt specifications for FRP, for use in state transportation construction projects?
- Tax an opportunity implemented in Australia soon in EU
- What is the estimated usage of competing bars? Epoxy coated, galvanized steel, stainless steel, multicoated?
- What are the market trends for FRP rebar?
- In Europe they control also the way in which you test the rebar for getting the certification

Education

- Suggestion: Hire a group representative to travel, educate, and train contractors etc. Need real customer!
- How can we educate Engineers of authorities about FRP rebar?
- Why do you feel we have such a hard time educating end user on FRP rebar?
- How contractors are incentivized for extended durability?
- How influential is FHWA over your use of GFRP?
- Open source design software tools
- Open source design software
- Share tools for designers
- Trust
- Steel design to FRP, back calculate
- Easy tools
- Is there a need for season sustainability in DOTs?
- How do losses in GFRP compare to traditional presentation?
- Reduction of the pH of the concrete: new blended cements, geopolymers, etc.
- What is the most effective means of dissipating energy when designing with GFRP rebar?
- Why Basalt is not as popular in US as it is in other parts of the world.
- GFRP for pre-stressing

Codes/Construction

- Is sustainability important only in the public sector?
- What is the density of GFRP compared with rebar?
- Why doesn't the DOT specify it on more projects?
- Liability: for multiple vendors in a project
- Should we engage the FHWA to help state DOTs with FRP?
- Difference in lap splices between ACI and other codes?
- Fire rating for FRP bars

Standards

- Harmonization of standards
- Product variability hinders standardization
- Standardization both of unit materials and design features
- Support basalt size standardization

Testing/Materials

- Combination of different kind of rebar (GFRP+BFRP and so on)
- Problem with manufacturers and insurers (if something happens, the fault is of GFRP or BFRP manufacturer?)
- Any research available for post-installed FRP applications with epoxy adhesives?
- Possibility to mix this technology with others, like FRC?
- Realistic modulus of elasticity
- Energy dissipation bend process tests on a field bent bar (thermoplastic)?
- Horizontal Shear Test: very nice to check all the properties of the rebar
- Hybrid rebar why not?
- Quality: Double verification by independent lab necessary? Since product rarely approved
- Is basalt better?
- Uniformity in material quality
- Fatigue test
- Pre-stressing with GFRP
- Quality control simplifications and implications
- How GFRP become alternate or base bid option?
- Better characterization of resins
- Simplify the moisture absorption test
- Durability in service
- What is the number one obstacle preventing the FRP rebar industry from accelerated growth?
- What is the real life durability of GFRP compared to the life of a building?
- Recycling issue
- True durability of FRP bars concerns me: No true long term data, failure is dramatic

- Do they last longer than concrete?
- What durability case history proof can we provide to end user concerns or needs?
- Pressures? Loss magnitude 20% creep!
- Earthquake/Seismic: cyclic loading, fatigue
- Post installed: repair, Canadian spec, rebar locators (vetrasonic)
- Accreditations in EU: to follow our method because there is over control along the process
- Infinite available materials
- Infinite compositions
- Hybrid FRP rebar
- Liability for multiple suppliers
- Simplicity and materials and standardization

Facilitate Customers
- Standardizing Format for presenting design data
- Implications of QC
- Finding reliable alternative
- Methods-doesn't mean to get an exact value, but a mid-point reliable value
- Acceptance timing: Moisture absorption test, reducing it to 24-hours
- Education of ENG: syllabus, influence market in class to general part of a class standard base
- Industry: cost, analysis with more factors, frequency (time), installing cost

Top Market Opportunity
- Top Obstacles?
- Durability examples proof?
- Customers in tech events
- Costs
- Speed rebar's production
- More case studies/projects as a model
- Proving calculations in LCC
- Simplify things for everybody
- Risk/Confidence

BFRP
- Basalt Rock: single component sustainability, high resistance to UV low
- Two times stronger in Tensile strength innovation bridge- precast slabs cost life cycle
- Quarter of the weight of steel
- Stirrups strength compared to steel
- Testing Needs?
- UHPC + Rebar FRP
- Saltwater + Rebar
- Isolation, Fire- insulation

Industry/Academia
- Collaboration
- Magnitude
- Interrelation collaborator
- Sharing is caring
- Education of designers
- Cost
- Fatigue/ creep rupture
- Publications

Certification
- Significance
- Durability
- Scope of work
- Material
- Durability
- Long term effects
- Costs
- Sizing of bars
- Production quality
- Fiber content (Bar size)
- Prequalified rebar and others
- Independent Certifier
- Certification on the way manufacturer control their production
- More open knowledge

QA/QC
- Double Verification
- Collective: Marketing
- Time to market: field test, research
- Cert.
- Durability
- Uniformity: Materials
- Protocol for QC

- KC-ES Test (ASTM)
- ACMA
- Tensile test problem
- High variance in results
- Specs
- Real need- standardize!
- Standards- high standards enforcement
- Certifications
- 440: Timeline, scope, significance high rise
- What designers need? Details, barriers
- Where? Every element
- QA/QC – during project -> (2+3) = confidence
- Steel industry is established; GFRP needs the same trust

3- **Extended off-line discussion** (with one of the attending rebar manufacturers)

- **ASTM D7957**

Tolerance for the cross-sectional area acceptance too high, no uniformity of the bars and in the elastic modulus.

Personally, I agree, but these are the values on which the industry has agreed. ASTMs are consensus standards.

DOTs do not perceive it as a problem as long as there are minimum and maximum diameters.

On the contrary, they are inclined to choose bars with higher nominal form as a consequence of a greater effective area compared to the nominal one.

I understand the problem of homogenizing production compared to the European market where I understand that the property will be guaranteed on the effective diameter.

- **ASTM D7205**

Calculation of the elastic modulus between 0.001 – 0.003 strain, initial part of the test, not representative of the bar behavior.

My opinion is that the range 0.001-0.003 corresponds to the operating conditions of the bar, so we have an accurate measurement of the elastic modulus in the conditions in which the bar works the most.

The elastic modulus thus calculated is typically higher than the elastic modulus at break, but this is in favor of safety because it provides a downward estimate of the ultimate load. ($\varepsilon_{fu} = f_{fu} / E_f$).

If all the laboratories were able to carry out deformation measurements until they were broken, the problem would not exist, but many of them prefer to avoid the risk of damaging the extensometers and even in this case those are consensual standards.

The real problem is if the elastic modulus should be calculated from the linear regression in the range 0.001-0.003 (as I think so) or should be calculated point by point (as ASTM seems to suggest).

In this case I can only think of an oversight of the regulator that should be resolved in the next version.

Note that the nomenclature of ASTM D7205 is obsolete (see for example the nominal diameter definition) and there is the intention to publish a short update which has been expressed.

I would advise you to take part in ASTM's work.

- **ASTM D7913 vs ASTM D7914**

Different values between the recommended tests: for the Bond, maximum aggregate size 20-25 mm, slump of 100 + - 20 mm, 28-day compression resistance of 30 + - 3 MPa, portland cement type I / II without other cementitious materials or additives; for the Brackets, maximum aggregate size 10-25 mm, slump of at least 100 + - 20 mm and 28-day compression resistance of at least 30 + - 3 MPa ("at least" but is there tolerance, writing error?)

I can only think of an oversight of the standard.

My personal position is that concrete requirements are not binding ("should" instead of "Shall"), but it is good to get as close as possible. Beware of those that are mandatory prescriptions, such as the imposition of CEM I or II.

In terms of pull-out, a possible problem that you will have to face in terms of EU / US alignment is the difference between ASTM and ISO. ISO provides the possibility of having transversal reinforcement, without imposing it, at least in the 2008 version.

- **ASTM D570**

Do you have to put resin in the cross sections of the specimens? it is not specified and different results are obtained; "dry the specimen with a dry pan, weigh immediately and then put back in water ..." PROBLEM: samples with sand, the water remains on the surface and the weight changes if you dry and weight immediately or dry and wait for minutes before weighing it.

Example 1: sample # 4 without resin on cross sections = test not passed (<1% weight increase at saturation), while # 4 with resin yes

Example 2: sample # 4 weighed immediately after drying = 6.425, after 5 minutes = 6.417, after 15 minutes = 6.411, after 30 minutes = 6.399 ...)

I would say no, I do not have to put resin. But it is not explicitly forbidden, on the contrary, no indications are given on how to adapt a standard written for plastics to bar portions.

Can be defended the position that sees the resin coating as a standard procedure in your production and it is legitimated the resin coating of the specimens for a better representativeness of the test.

- **ASTM D7705**

recommended alkaline solution (118.5 g of CaOH2, 0.9 g of NaOH and 4.2 g of KOH per liter of tap water), lime deposited and tap water does not allow to control the pH (better distilled water); pH to be monitored at ambient T or at 60 ° C (test)? (the measured values change! 12.68 vs 12.27); finally, it is said to test the tensile bars after 24h from the end of the test, but to make the anchors they need at least 24h + 24h ...

The recipe wants to "simulate" the solution in the pores of a typical concrete. On how much this makes sense I cannot say.

I do not understand why accurate ratios are provided between reacting powders and then going to unbalance the reaction making it impossible to guarantee that the reactions take place in the prescribed ratios.

The use of tap water I think is aimed at "simulating" and not to simplify the procedure. Compared to the previous point, I do not see any critical point.

I imagine that the pH should be controlled at 60 ℃, but I remember you told me that it is not possible to maintain a pH of 12.6 to 60 ℃.

Furthermore, it is impossible to make, an already over-saturated solution, more alkaline.

In general, my opinion is that these are oversights of the regulator that should be corrected with an update of the law.