Third International Workshop on FRP Bars for Concrete Structures (IW-FRPCS3)

Workshop Theme: "Advances in concrete reinforcement"

Date: August 3-4th, 2021

DAY 2 Wednesday, August 4th

Session 4: Advancing FRP Rebar Manufacturing & Product Development to meet Market Needs (8:15-9:45am EDT)

(What is new, better, and scalable?)

RoundTable discussion with audience participation, preceded with 3-minute introduction by panelists.

Moderator: John Busel (ACMA)

Panelists (5 mins)

- Higher Performing Bent Bars: Borna Hajimiragha (B&B)
- Why should we consider epoxy: Bhavesh Muni (Olin)
- How can thermoplastics help: Paolo Casadei (SIREG)
- What other fibers to consider: Mike Levine (MAFIC) No slides
- Why not filament winding for closed stirrups: Don Smith (RAW) No slides
- Ensuring QC and Scalability: Bernard Drouin (Pultrall)

THIRD INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURS

“Advances in concrete reinforcement”

August 3-4, 2021 - Virtual

High Performance Bent Bars

Borna Hajimiragha, B&B FRP Manufacturing Inc.(MST-BAR), Toronto

8 am Aug 4th

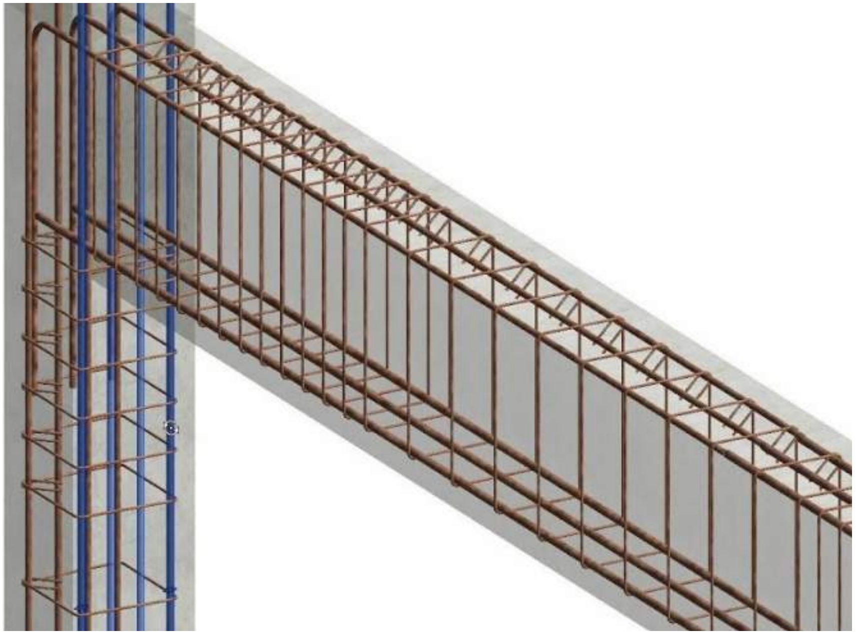
Topics

- Bent bar primary use
- High performance bent bar
- Alternative to bent bars
- Mechanical connection
- When is good enough good enough?
- Scalability and Reality

Bent Bar Primary use

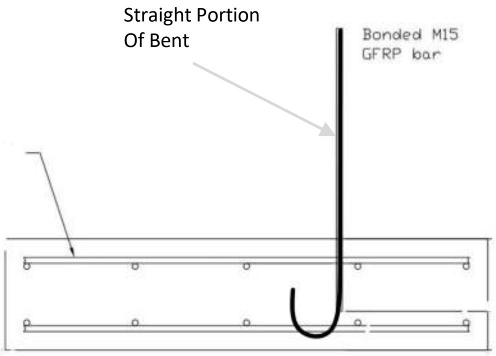
Bent bars predominantly use for

- Anchorage (Connecting two components)
- Confinement & Shear
- Chair and placement of other rebar

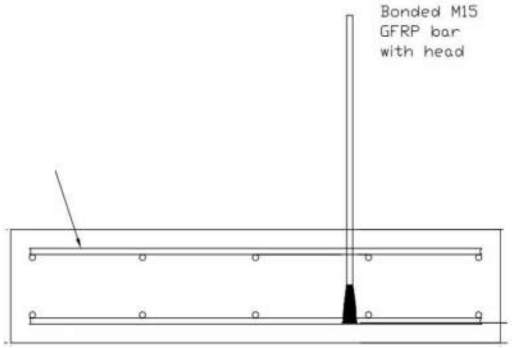


Anchorage of GFRP!

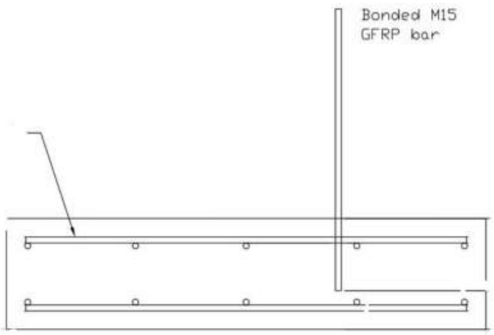
- Anchorage (Connecting two components)



Bent Bar



Anchor Head



Straight Bar

High Performance Bent

Tested on #3,#4,#5 and #6

Straight Portion of the Bent

- Strength, Shear, Bond

LOT No.1

LOT No.2

LOT No.3

Straight Portion of the Bent

- Strength, Shear, Bond

Specimen	Lot #	Maximum tensile load (kN)	Ultimate tensile strength (MPa)	Tensile elastic modulus (GPa)	Ultimate tensile strain (%)
1	1	413	1454	57	2.6
2		393	1384	55	2.5
3		387	1363	55	2.5
4		404	1423	51	2.8
5		414	1458	54	2.7
6		346	1218	53	2.3
7		371	1306	53	2.5
8		377	1327	55	2.4
Average		388	1367	54	2.5
SD		23.2	81.6	1.7	0.16
COV %		6.0	6.0	3.1	6.2
1	2	352	1239	51	2.4
2		361	1271	55	2.3
3		366	1289	54	2.4
4		366	1289	57	2.3
5		373	1313	54	2.4
6		415	1461	51	2.9
7		340	1197	55	2.2
8		365	1285	56	2.3
Average		367	1293	54	2.4
SD		21.8	76.9	2.0	0.21
COV %		5.9	5.9	3.7	8.7

Table 2 - Tensile Strength of Bent Portions of MST GFRP Bent Bars #6 (Nominal Area 284 mm²)

Specimen	Lot #	Maximum load (kN)	Ultimate tensile strength (MPa)
1	1	254	894
2		262	923
3		278	979
4		258	908
5		251	884
6		243	856
7		267	940
8		251	884
Average		258	908
SD		10.9	38.5
COV %		4.2	4.2
1	2	263	926
2		241	849
3		250	880
4		233	820
5		229	806
6		231	813
7		248	873
8		242	852
Average		242	853
SD		11.4	40.2
COV %		4.7	4.7

Table 3 – Summary of Average Tensile Strength of Straight and Bent Portions of MST GFRP Bent Bars #6

Lot #	Average Tensile Strength of Straight Portion (MPa)	Average Tensile Strength of Bent Portion (MPa)	Bent Strength Ratio (%)
1	1367	908	66
2	1293	853	66

Straight Portion of the Bent

- Shear (CSA S807-19 :180MPa)

***Table 1**: Summary of experimental results of the transverse shear strength of the straight portion of 15 mm (#5) MST-BAR® BEND GFRP bent bar*

Specimen	LOT No.1		LOT No.2		LOT No.3	
	Failure Force kN	Transverse Shear Strength MPa	Failure Force kN	Transverse Shear Strength MPa	Failure Force kN	Transverse Shear Strength MPa
SAMPLE 01	80.41	202.0	90.3	226.9	87.08	218.8
SAMPLE 02	84.65	212.7	84.65	212.7	86.77	218.0
SAMPLE 03	82.37	207.0	87.4	219.6	84.45	212.2
SAMPLE 04	85.4	214.6	80.98	203.5	84.53	212.4
SAMPLE 05	82.3	206.8	81.3	204.3	83.22	209.1
SAMPLE 06	81.45	204.6	82.75	207.9	81.64	205.1
SAMPLE 07	81.83	205.6	78.15	196.4	85.99	216.1
SAMPLE 08	78.13	196.3	80.3	201.8	83.76	210.5
Average	82.1	206.2	83.2	209.1	84.7	212.8
Standard Deviation	2.1	5.4	3.8	9.4	1.7	4.4
Coefficient of Variation (%)	2.6	2.6	4.5	4.5	2.1	2.1

Buckling

- Is it possible to Avoid?
- How important it is to prevent buckling?
- Size and Bent radius?

How Tight of Radius

- Is it possible to?
- Is it cost effective?

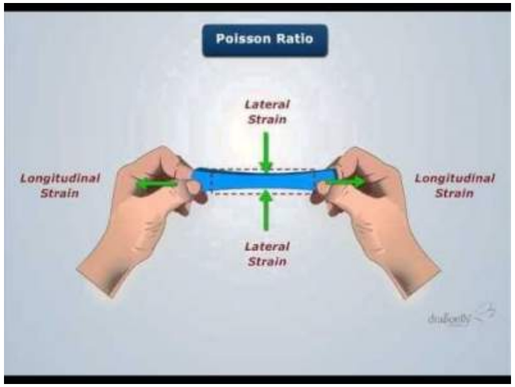
How Crazy?

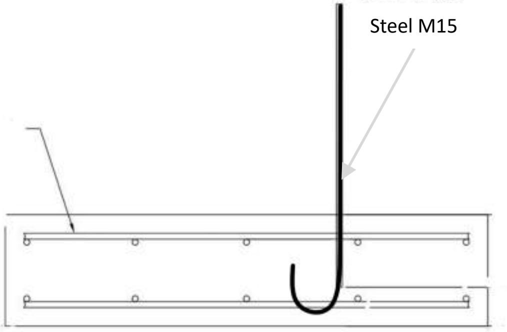
- Complexity of the Bend?
- Cost Vs. Quantity?

How about this?

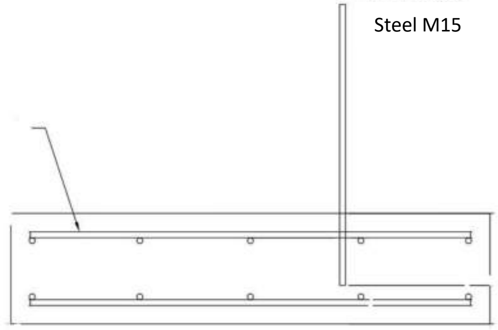
Steel: When is Good enough, Good enough!

- Anchorage (Connecting two components)





500MPa = 100kN 15M
Steel fails

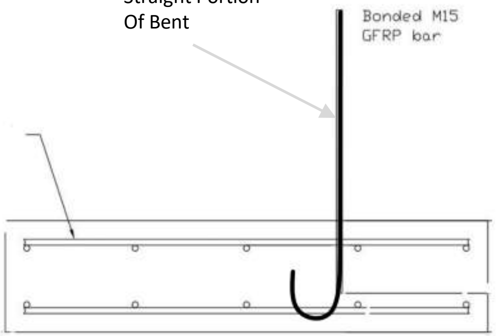


Steel Pull out 45kN at 100mm Embd.

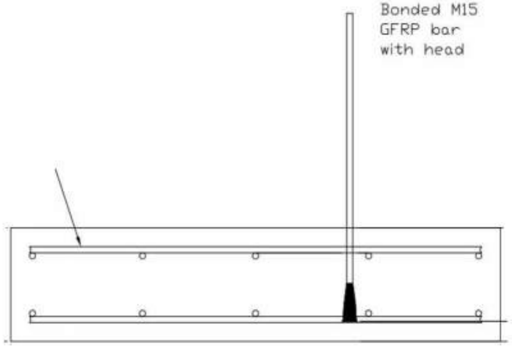
When is Good enough, Good enough!

- Anchorage (Connecting two components)

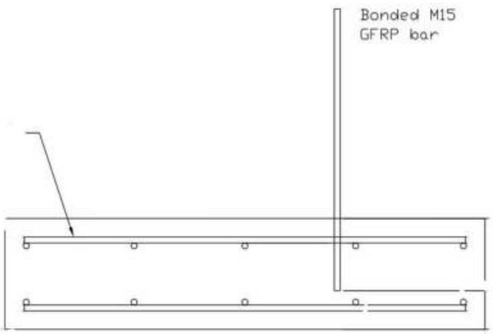
Why? **Low Passion's Ratio**
High Bond strength



100kN-based on 500MPa
Strength at bend
160kN-based on 800 MPa
Strength at bend
200mm and more embed. required



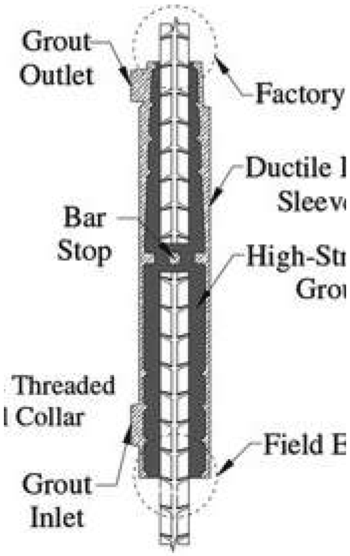
100kN
100mm Embd.



150kN at 100mm Embd.
For fully threaded integral rib
Before concrete breaks

Mechanical Coupler

- Grout Coupler Tested with
  - Off the Shelf High Strength Concrete
  - Test performed on #5 with standard #5 coupler



Grouted Sleeve Coupler (GC)

Mode of Failure

- Concrete Shear inside the coupler @ 3.5'' each side 140kN
  - Off the Shelf High Strength Concrete
  - Test performed on #5 with standard #5 coupler

  - 140kN(31,500lbf) – inline with design strength
  - Not Meeting 1.2 x UTS

  - Solution: Making the grout coupler longer
  - Solution: Higher Concrete Strength/UHPC

Scalability and Reality

- Quantity
- Price
- Geometry

Scalability and Reality

If this can be done perfectly?

Can this be done perfectly too?

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Epoxy For FRP Rebar

Bhavesh Muni & Huifeng Qian, Olin Epoxy, USA

About Olin

ONLY BACK-INTEGRATED GLOBAL EPOXY PRODUCER

8,000 + EMPLOYEES

HQ in U.S.

LEADING THE WAY IN EPOXY since the 1950s

SUPERIOR LOGISTICS NETWORK

PRODUCTION AND TECHNOLOGY LABS ON FOUR CONTINENTS

R&D COLLABORATION
Investing in technology and working closely with customers to develop game-changing solutions

ON THE NYSE FOR >100 YEARS

Composites based on Epoxy matrices have been used in various applications with extreme durability.

WHY EPOXY FOR FRP REBAR?

VERSATILE CURE AND PROCESSING

EXCELLENT FATIGUE AND MECHANICAL PERFORMANCE

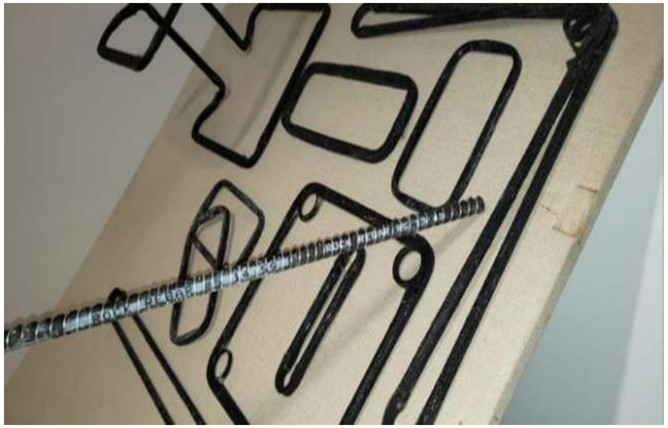
HIGH CORROSION RESISTANCE

STYRENE AND VOC FREE

SUPPLY CHAIN RELIABILITY

REBAR PERFORMANCE – PRE ALKALINE TREATMENT

Methods	Test Description	SPEC. FDOT 932	Test Values	Comment
ASTM D7617	Guar. Transverse Shear Strength	>19 ksi	21.0 ksi	Pass
ASTM D2584	Fiber Content (by weight)	>70 %	79.8 %	Pass
ASTM D7205	Guar. Tensile Force	29.1 kip	33.1 kip	Pass
	Tensile Modulus of Elasticity	≥ 6.5 Msi	7.0 Msi	Pass
	Tensile Strain	≥ 1.1%	1.6 %	Pass
ASTM D792	Measured Cross Sectional Area	0.288 to 0.388 in^2	0.292 in^2	Pass
ASTM D570	Moisture Absorption Short Term	≤ 0.25 %	0.17 %	Pass
	Moisture Absorption Long Term	≤ 1.00 %	0.67 %	Pass
ASTM D7913	Guar. Bond Strength	>1100 psi	1227 psi	Pass
ASTM E2160	Degree of Cure	>95%	99.1 %	Pass
	Glass Transition Temperature (DSC)	>100 ^oC	139 ^oC	Pass



Basalt fiber: FVF 60-65%
Estimated Line Speed : 1-2 m/min
Tested in University of Miami

REBAR PERFORMANCE – POST ALKALINE TREATMENT

Test Method	Test Description	Spec. FDOT 932	Values	Result
SAMPLE #3				
ASTM D7205	Tensile Load Retention (with load)1	>70 %	78.3 %	Pass
ASTM D7617	Trans. Shear Strength Retention	n/a	84.2 %	n/a
ASTM E2160	Degree of Cure	>95 %	99.06 %	Pass
	Glass Transition Temperature (DSC)	>100 °C	139 °C	Pass
SAMPLE #4				
ASTM D7705	Tensile Load Retention (with load)1	>70%	92.3 %	Pass
ASTM D7617	Trans. Shear Strength Retention	n/a	107.6 %	n/a
ASTM E2160	Degree of Cure	>95 %	99.4 %	Pass
	Glass Transition Temperature (DSC)	>100 °C	128 °C	Pass
SAMPLE #5				
ASTM D7705	Tensile Load Retention (with load)1	>70 %	89.8 %	Pass
ASTM D7617	Trans. Shear Strength Retention	n/a	106.2 %	n/a
ASTM E2160	Degree of Cure	>95 %	99.1 %	Pass
	Glass Transition Temperature (DSC)	>100 °C	139 °C	Pass

Epoxy Rebar with *LITE***STONE™** 3200E/2131H exceeds or meets FDOT 932 specs

For Further information and discussion, Please contact

Bhavesh H. Muni

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Tel: 562-412-9962

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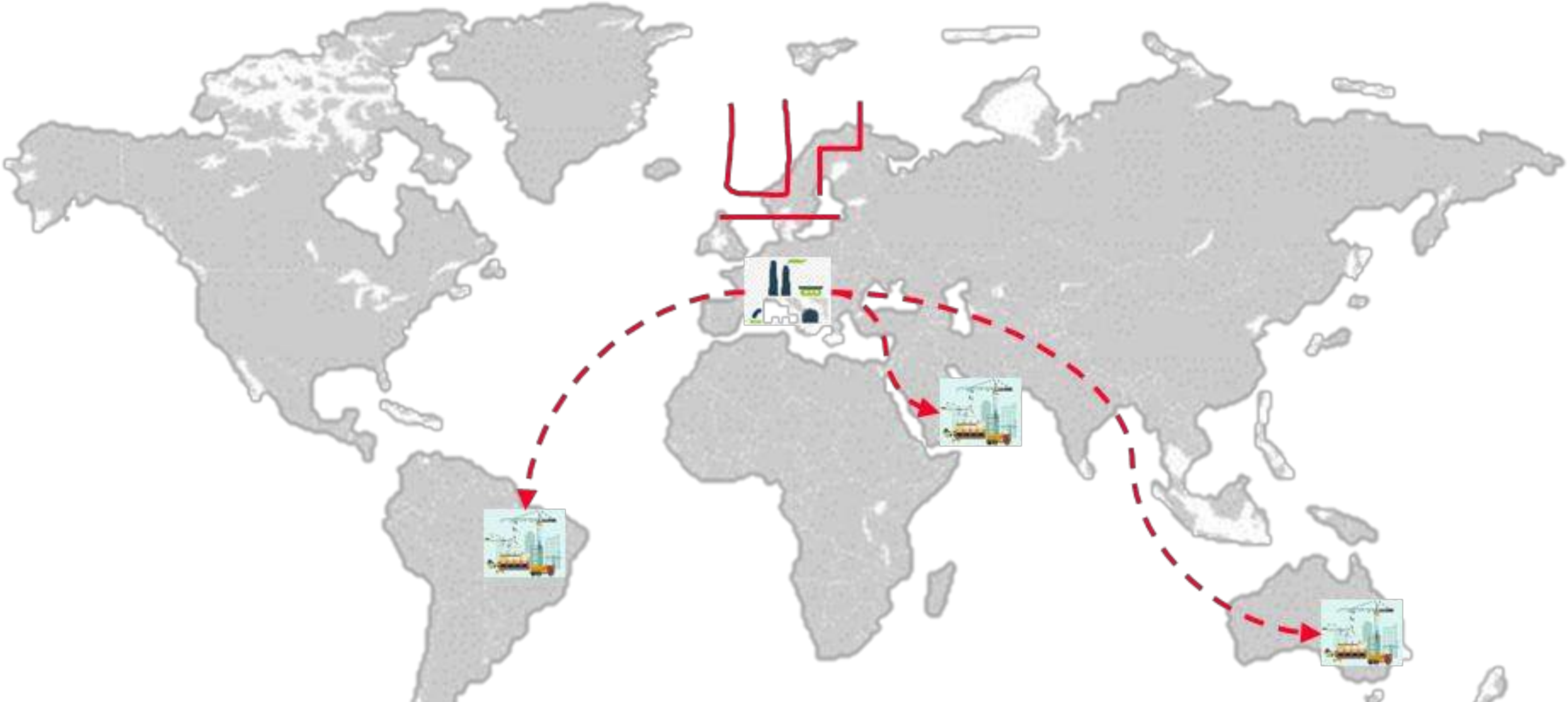
How thermoplastic GFRP can help

Paolo Casadei Ph.D. P.E., SiregGeotech, Italy

Why GFRP rebars are currently implemented mainly in straight applications such as decks and slabs, with limitations as stirrups and bent portions?

FRP REBAR CURRENT MANUFACTURER MODEL



- Rebars are not bendable after curing of the resin (thermoset – irreversible hardening):
  - Production of straigth rebars shipped to contractor on-site
  - If stirrups are needed, manufacturer needs to receive technical drawings to produce accordingly!

FRP CURRENT LOGISTIC LIMITATIONS

CURRENT FRP REBARS WITH THERMOSET RESIN (Vinilester/Epoxy) CANNOT BE BENT LOCALLY BUT ONLY AT MANUFACTURING SITE which causes:

- Longer lead time for bending & shipping
- Higher transportation costs (volumes)
- More difficult overall logistic if something goes wrong

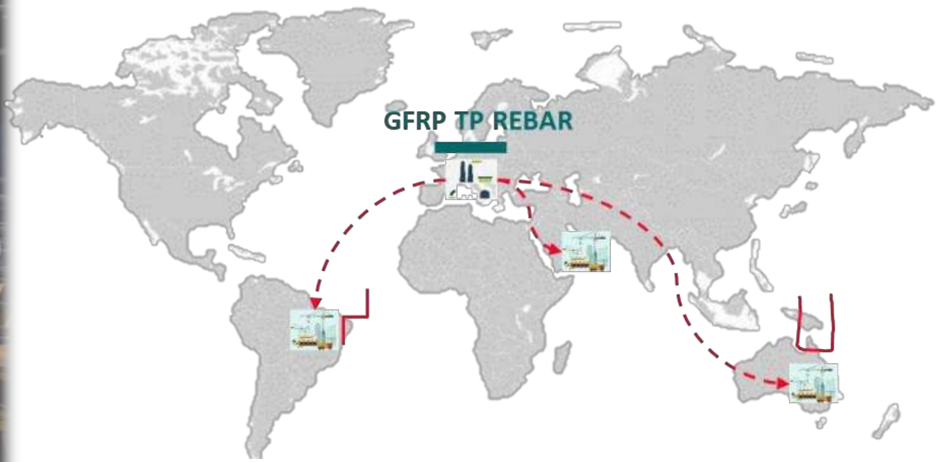
THERE ARE ALSO TECHNICAL LIMITATIONS :

- Not constant quality of the bended rebars
- Lower mechanical properties of the bended rebars compared to straight rebars
- Large bent radius which limits the positioning of longitudinal rebars

HOW CAN WE OVERCOME THOSE DIFFICULTIES?

<u>WE NEED TO BE ABLE TO FOLLOW THE SAME BUSINESS MODEL OF STEEL REBARS</u>: Rebars are manufactured straight and then shipped to «Transformation centers» which bend rebars, based on design, and prepare cages to be shipped on site.

<u>CERTIFIED TRANSFORMATION SITES</u> ARE DISLOCATED LOCALLY IN THE TERRITORY



THERMOPLASTIC REBAR REVOLUTION

NEW BUSINESS MODEL

FROM MAKE-TO-ORDER INTO MAKE-TO-STOCK

Supply chain model: we can switch from the current make-to-order model, with lead time of **3-4 weeks**, to a make-to-stock model.

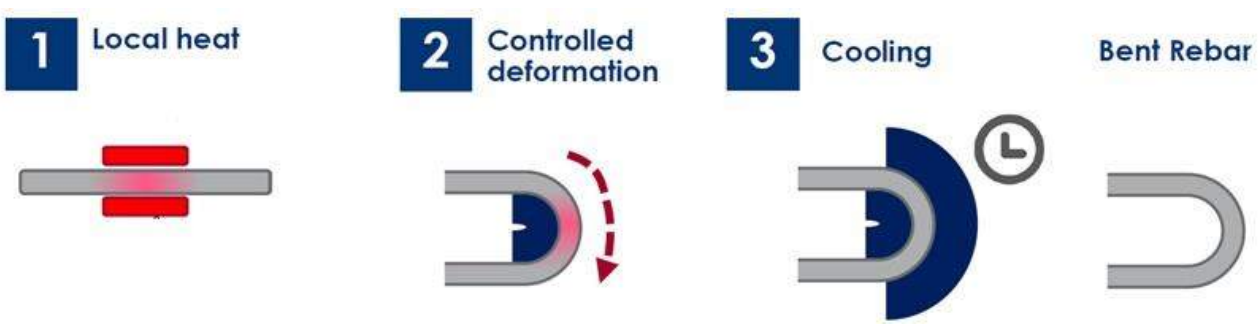
Lead Time 3-4 days

Manufacture and storage of **straight rebars or coils** → Shipping to **bending and distribution** centers → Bend the rebars into their **final shapes** → Shipping to construction sites / final customer

NEW BENDABLE FRP REBARS

REPLACING THERMOSET RESIN BY THERMOPLASTIC RESIN, FRP REBARS BECOME BENDABLE LOCALLY!

- Resin is soften by heat and thermoformable (thermoplastic – reversable hardening):
  - When stirrups/bent bars are needed, manufacturer produces straight rebars shipped straight or in coils (to avoid waste) to certified transformation centers that will bent them locally just like they do with steel.



NEW BENDABLE FRP REBARS

WHAT ABOUT MECHANICAL-DURABILITY PROPERTIES?

- ✓ **SIMILAR OR BETTER MECHANICAL PROPERTIES** than of thermoset rebars;
- ✓ **BENT BARS HAVE SAME MECHANICAL PROPERTIES OF STRAIGTH REBARS** as they are the same rebar simply bent after production – no difference whatsoever respect to straight rebars (no need of having two standards for straight and bent bars).
- ✓ **BENT RADIUS SIMILAR TO STEEL** – allows improving placement of flexural rebars and the overall optimization of design process;
- ✓ Surface treatment to obtain **SAME BONDING** to concrete of thermoset rebars;
- ✓ **Same DURABILITY PROPERTIES** of thermoset rebars (Alkaline and long term behaviour tested)

NEW BENDABLE FRP REBARS

WHAT ABOUT SUSTAINABILITY?

- ✓ **THERMOPLASTIC REBARS ARE RECYCLABLE !!!**
  - ✓ **Mechanical recycling compounds**
  - ✓ **Chemical recycling**

THANK YOU!

sireg
Geotech S.r.l.

Sireg Geotech S.r.l.
Phone: **+39 039 627021**
E-mail: **info@sireg.it**
Website: **www.sireggeotech.it**

PULTRALL

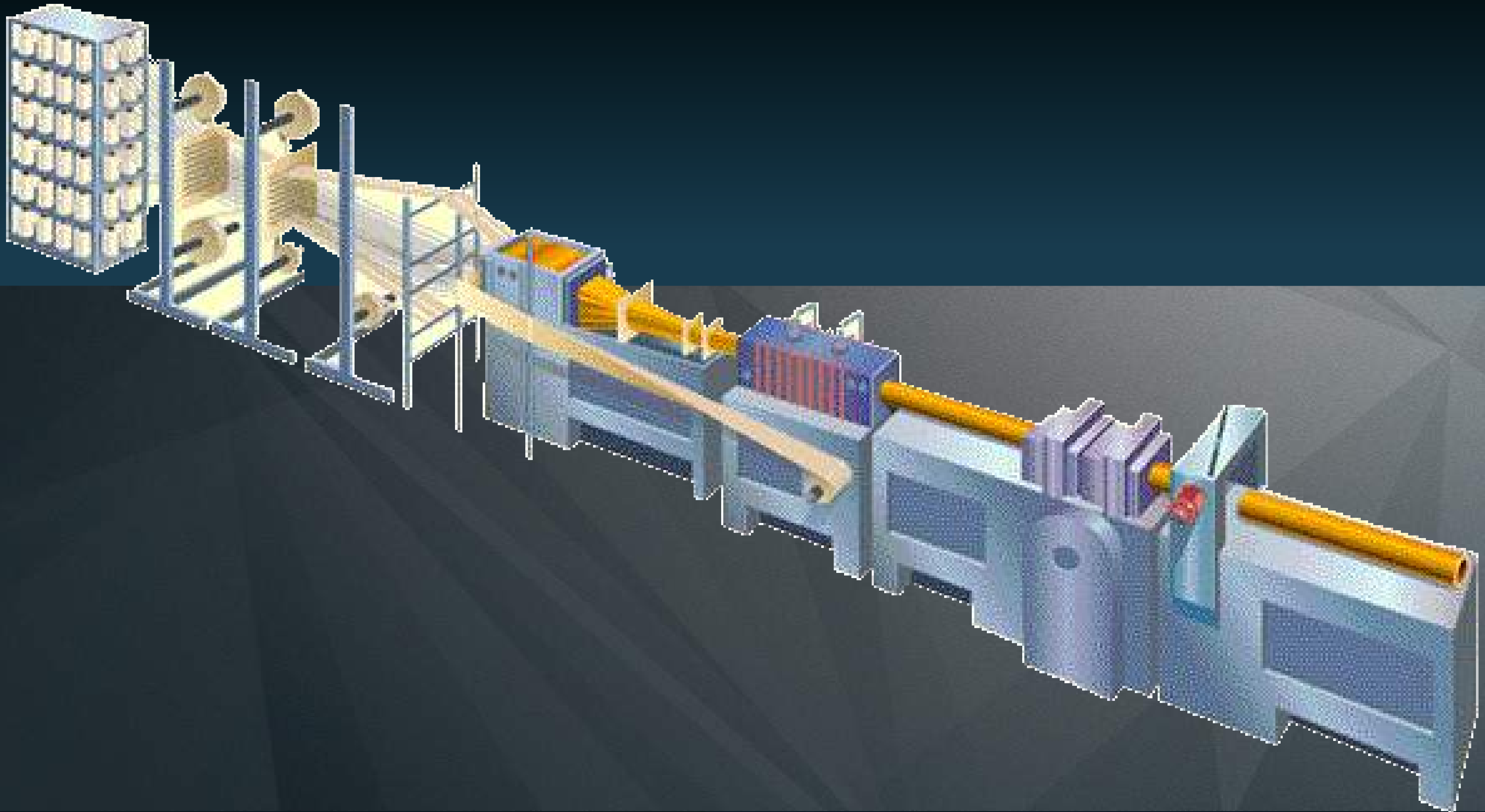
STRONG and FLEXIBLE

FRP Rebar Composition

Fibres (Reinforcements)
Resins (Polymers)
Fillers
Additives

Fibres – Mechanical strength
Resins – Chemical resistance

The process : Pultrusion



Manufacturing of V-Rod bars

↓

Inspection of raw material

↓

Resin mix

↓

Machine setup

↓

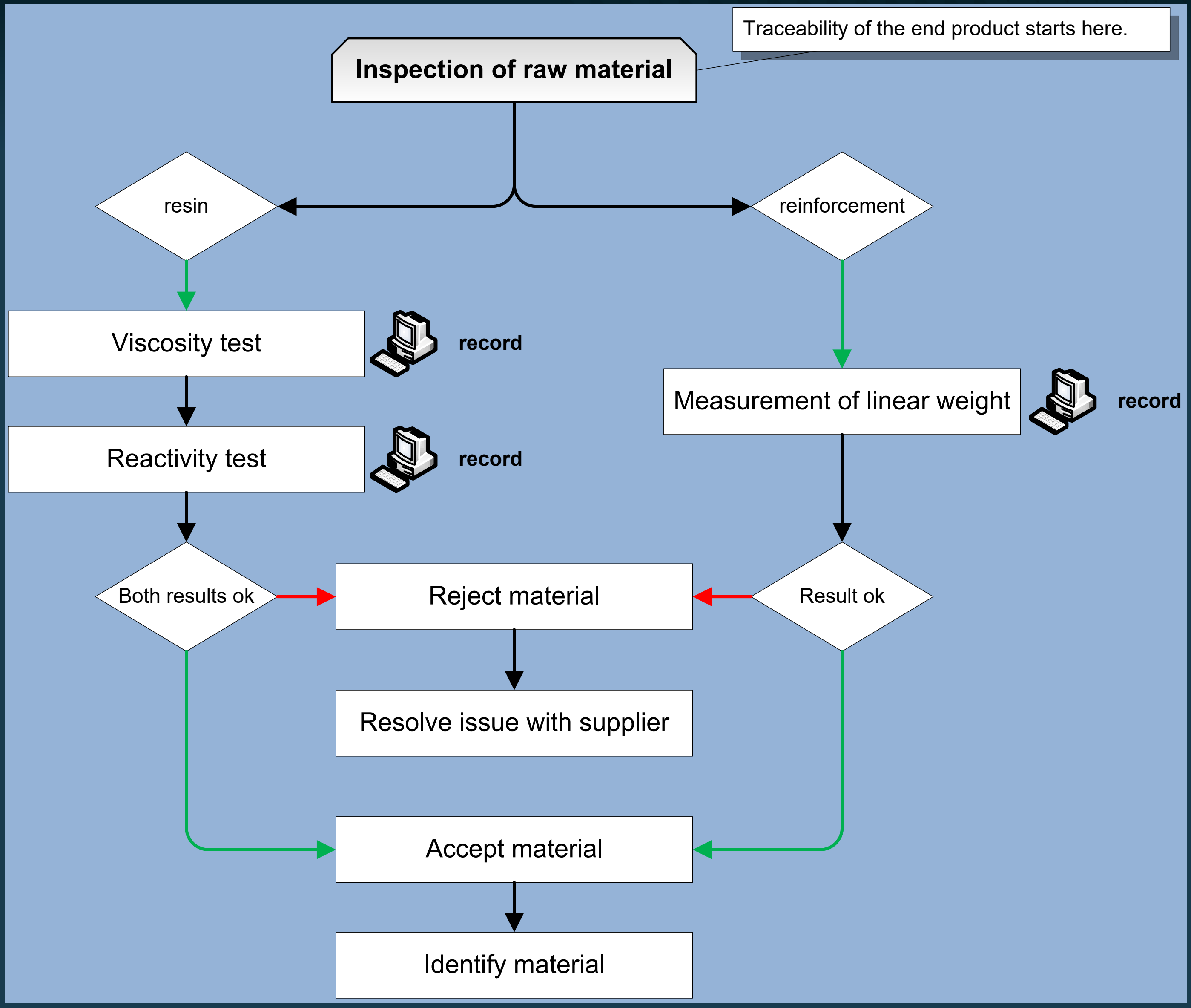
Start of production

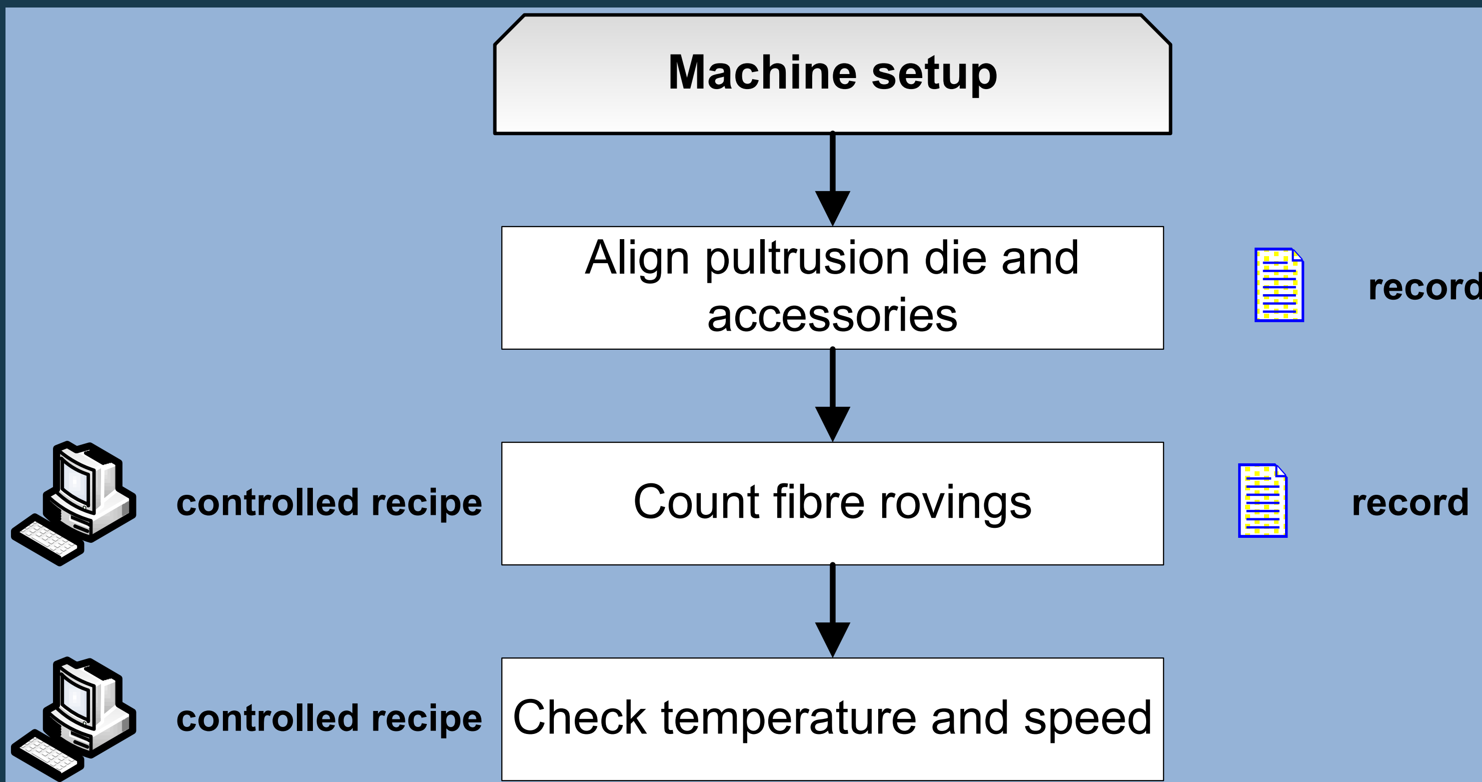
↓

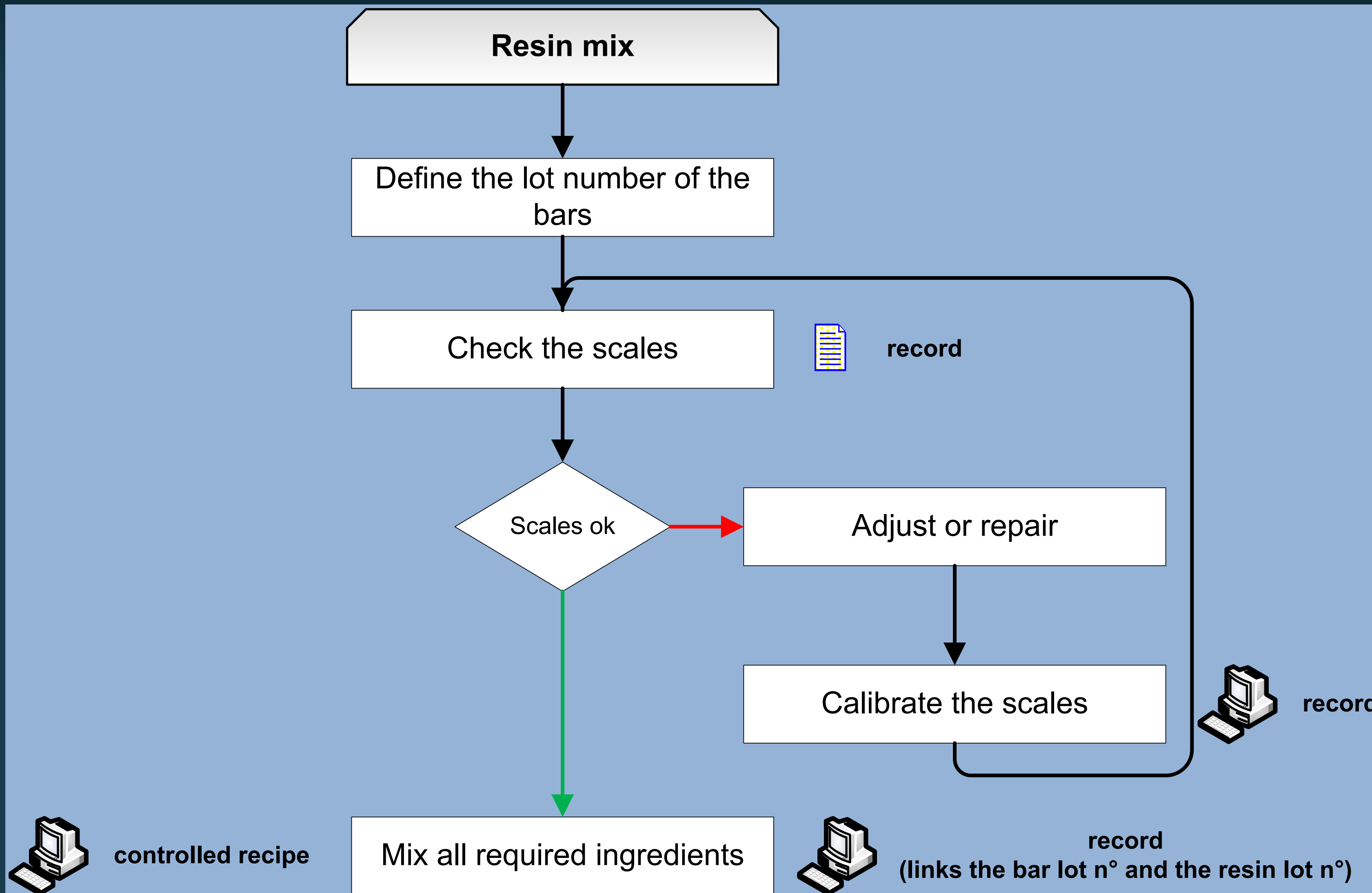
Production

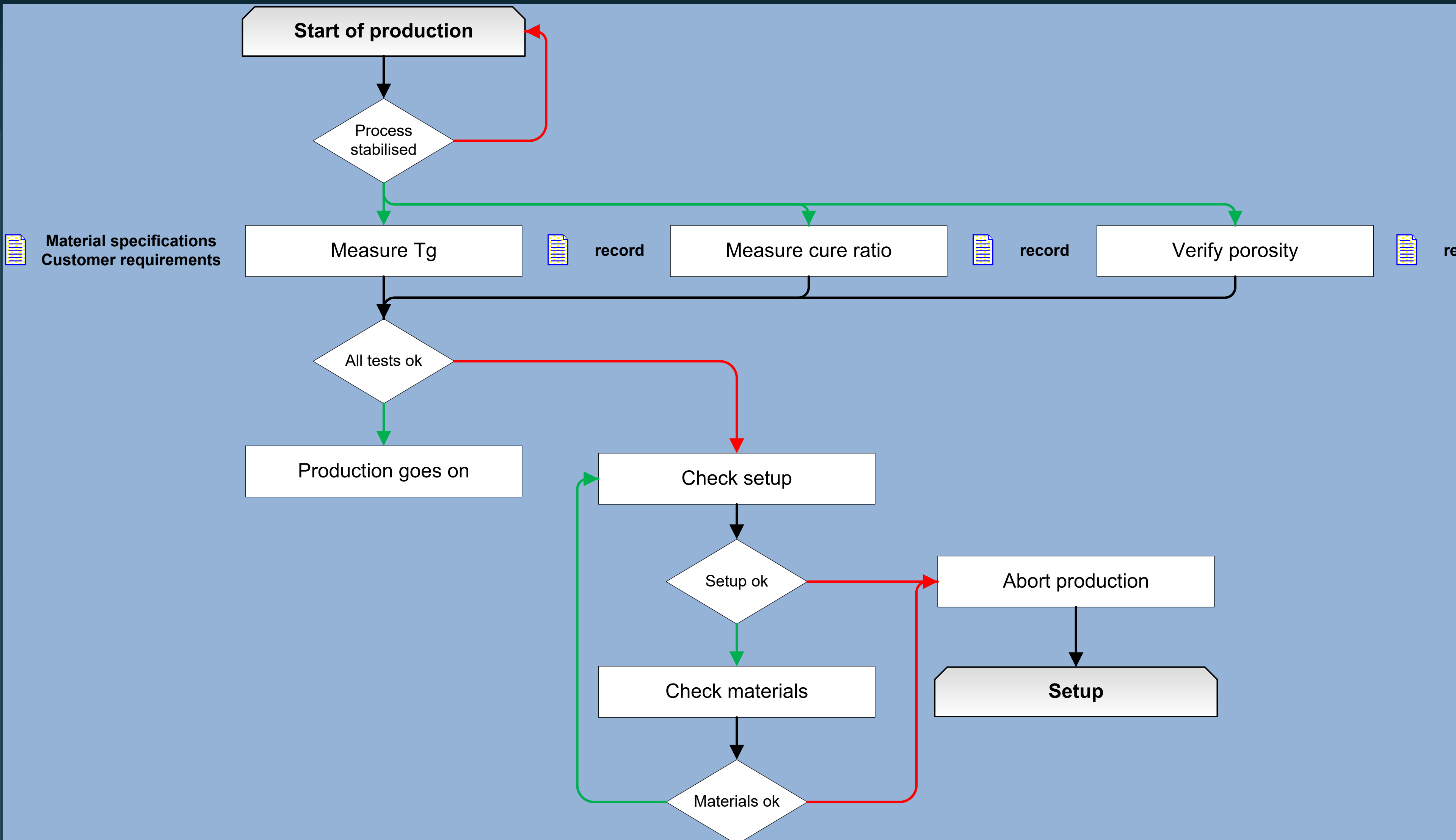
↓

Final inspection


Traceability of the end product starts here.
Inspection of raw material
resin
reinforcement
Viscosity test
record
Reactivity test
record
Measurement of linear weight
record
Both results ok
Reject material
Result ok
Resolve issue with supplier
Accept material
Identify material

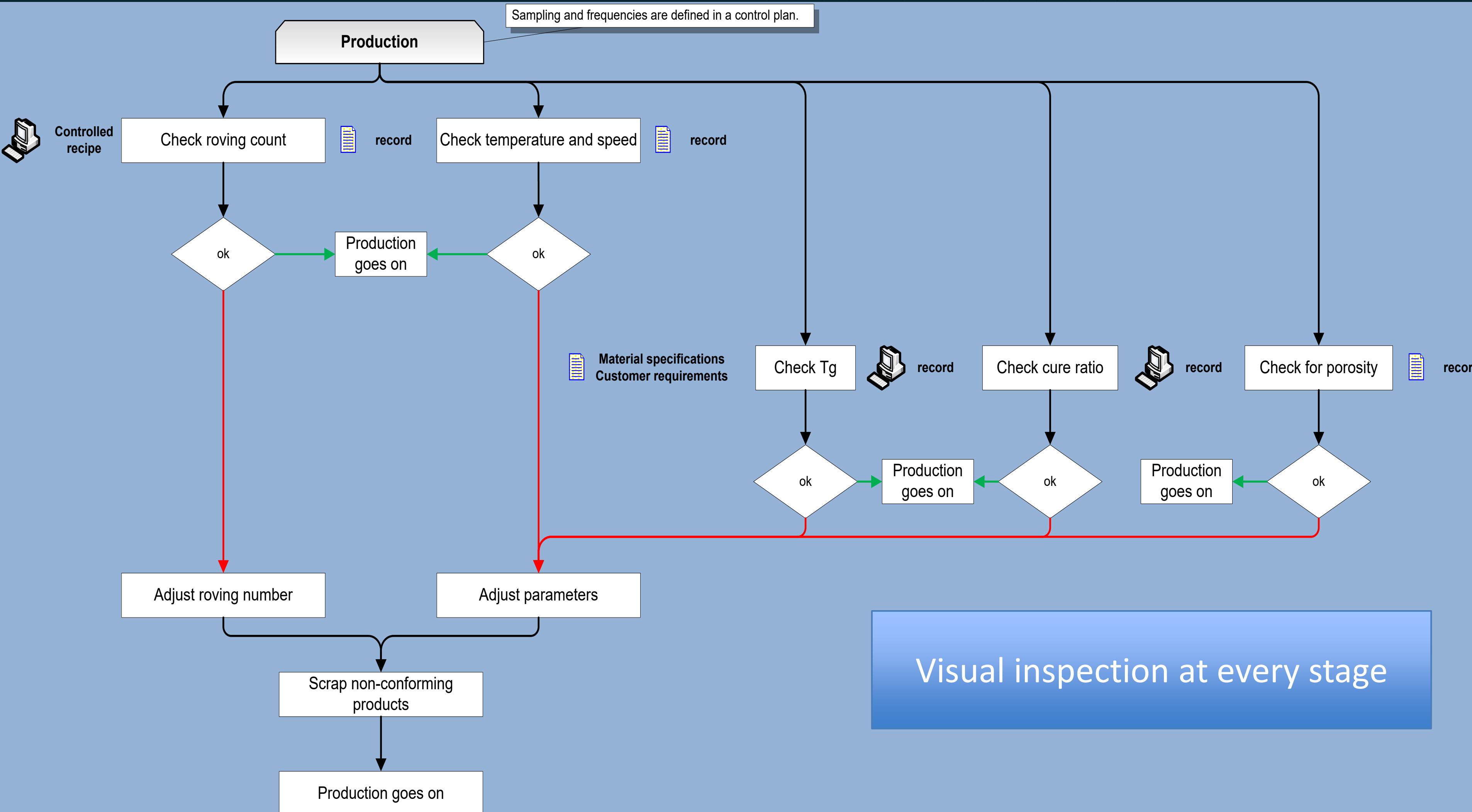

Machine setup
Align pultrusion die and accessories
record
controlled recipe
Count fibre rovings
record
controlled recipe
Check temperature and speed


Resin mix
Define the lot number of the bars
Check the scales
record
Scales ok
Adjust or repair
Calibrate the scales
record
controlled recipe
Mix all required ingredients
record
(links the bar lot n° and the resin lot n°)

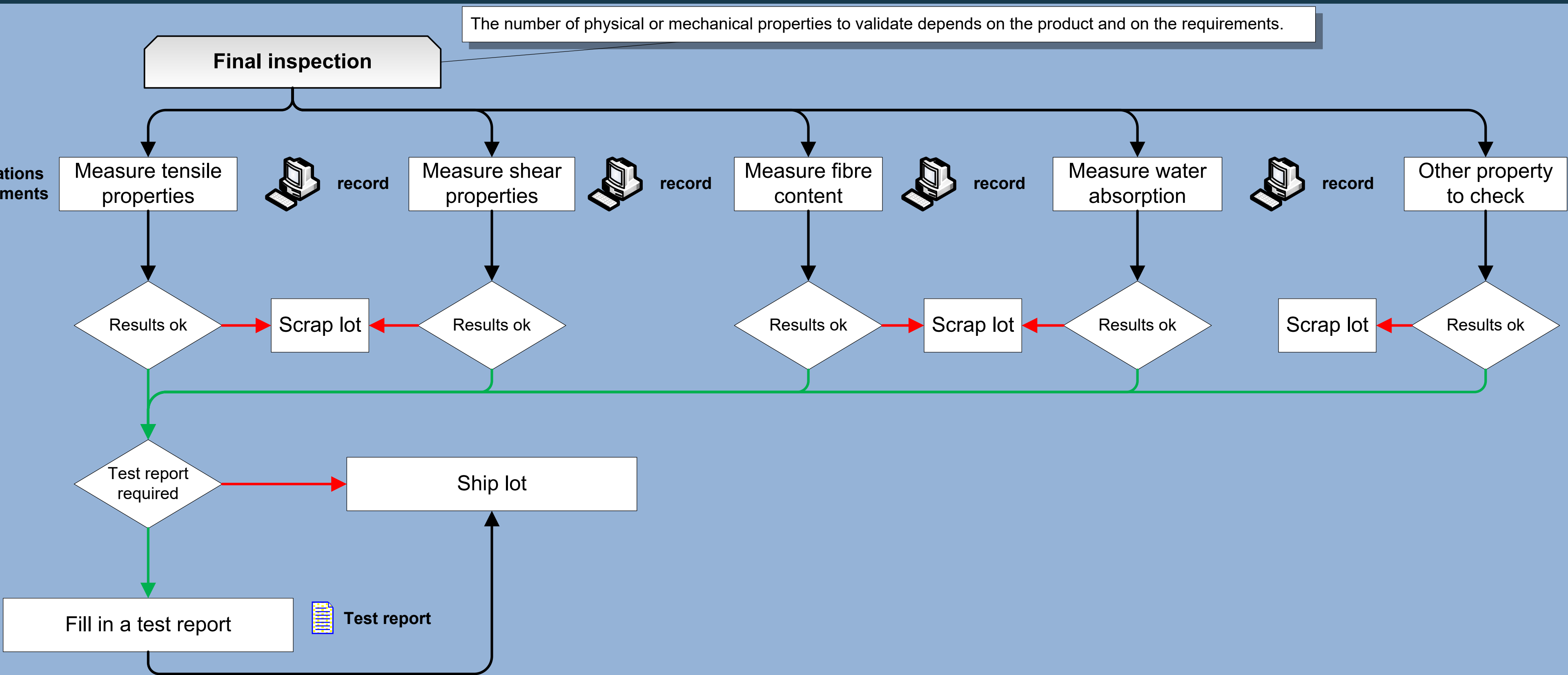


Start of production
Process stabilised
Material specifications
Customer requirements
Measure Tg
record
Measure cure ratio
record
Verify porosity
All tests ok
Production goes on
Check setup
Setup ok
Abort production
Check materials
Setup
Materials ok

PULTRALL



Visual inspection at every stage


The number of physical or mechanical properties to validate depends on the product and on the requirements.
Final inspection
ations
ments
Measure tensile properties
record
Measure shear properties
record
Measure fibre content
record
Measure water absorption
record
Other property to check
Results ok
Scrap lot
Results ok
Results ok
Scrap lot
Results ok
Scrap lot
Results ok
Test report required
Ship lot
Fill in a test report
Test report

Materials

bar #5 grade III

type of resin: vinylester, lot number 1702193P

type of fibre: glass

Production

manufacturing process: pultrusion

lot number: 1711002-5-60 with a total of m, started on and ended on .

a production lot is defined by a change of the lot number of the resin and/or a change of machine

Product characterisation

Cross sectional area:

test method CSA S806 Annex A

sample	mm²
1	226
2	225
3	227
4	224
5	224
average	225
std deviation	1,1
required minimum:	*189,1*
required maximum:	*238,8*

Longitudinal tensile properties:

test method CSA S806 Annex C

sample	load at break (kN)	strength (MPa)	modulus (MPa)	elongation (m/m)
1	279	1411,2	61670	2,3%
2	284	1435,3	61876	2,3%
3	293	1478,3	61526	2,4%
4	297	1499,2	62190	2,4%
5	282	1422,2	61624	2,3%
average	286,9	1449,2	61777	2,3%
std deviation	6,7	33,8	236	0,1%
required minima:	*200*		*60000*	*1,2%*

Transverse shear strength

test method ACI 440.3R test method B4

sample	load at break (kN)	strength (MPa)
1	96,6	244,0
2	99,9	252,4
3	97,9	247,3
4	97,1	245,4
5	97,0	245,2
average	97,7	246,8
std deviation	1,2	2,9
	required minimum:	*180*

Fibre content (per weight):

test method ASTM D2584 (temp 650°C, sand coating discarded from result)

sample	%
1	83,4%
2	83,8%
3	83,9%
4	83,4%
5	83,5%
average	83,6%
std deviation	0,2%
required minimum:	*70%*

Void content:

test method ASTM D5117 (15 min w icking w ith basic fuchsin)

sample	wicking
1	ok
2	ok
3	ok
4	ok
5	ok

Water absorption:

test method ASTM D570 (50°C)

sample	weight variation 24h	weight variation long term
1	0,06%	0,12%
2	0,06%	0,10%
3	0,07%	0,11%
4	0,07%	0,11%
5	0,07%	0,12%
average	0,07%	0,11%
std deviation	0,00%	0,01%
required minima:	*0,25%*	*0,45%*

Cure ratio and glass transition temperature:

test method ASTM D3418 and CSA S807 Annex A (half-height @ 20°C/min)

sample	cure ratio (%)	Tg (°C)
1	99,90	138
2	99,61	134
3	99,68	129
4	99,73	131
5	99,51	127
average	99,69	131,7
std deviation	0,13	3,7
required minima:	*95*	*100*

The quality system

- ISO9002-1994
  since 1994
- ISO9001-2000
  since 2003
- TS16949
  since 2008
- ISO14001
  since 2016

Certification

V-ROD is CSA-S807-10 and ASTM-D7957 certified

PULTRALL

Conclusion

- The quality system should be independently audited annually
- The product range should comply with CSA-S807 and ASTM D7957 (independently tested by a third party).
- Every manufacturing step should be subjected to inspections

STRONG and FLEXIBLE

Thank you