
CERN

Study of delamination between inner layer trace and inner impregnation layer after quench training of MQXFS coils

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CONTEXT OF THE STUDY

Starting point: disassembly of MQXFS1 and MQXFS3 magnets

- For visual inspection
- After quench training at cryogenic temperatures

Striking observation : partial delamination of inner layers on all 8 coils !

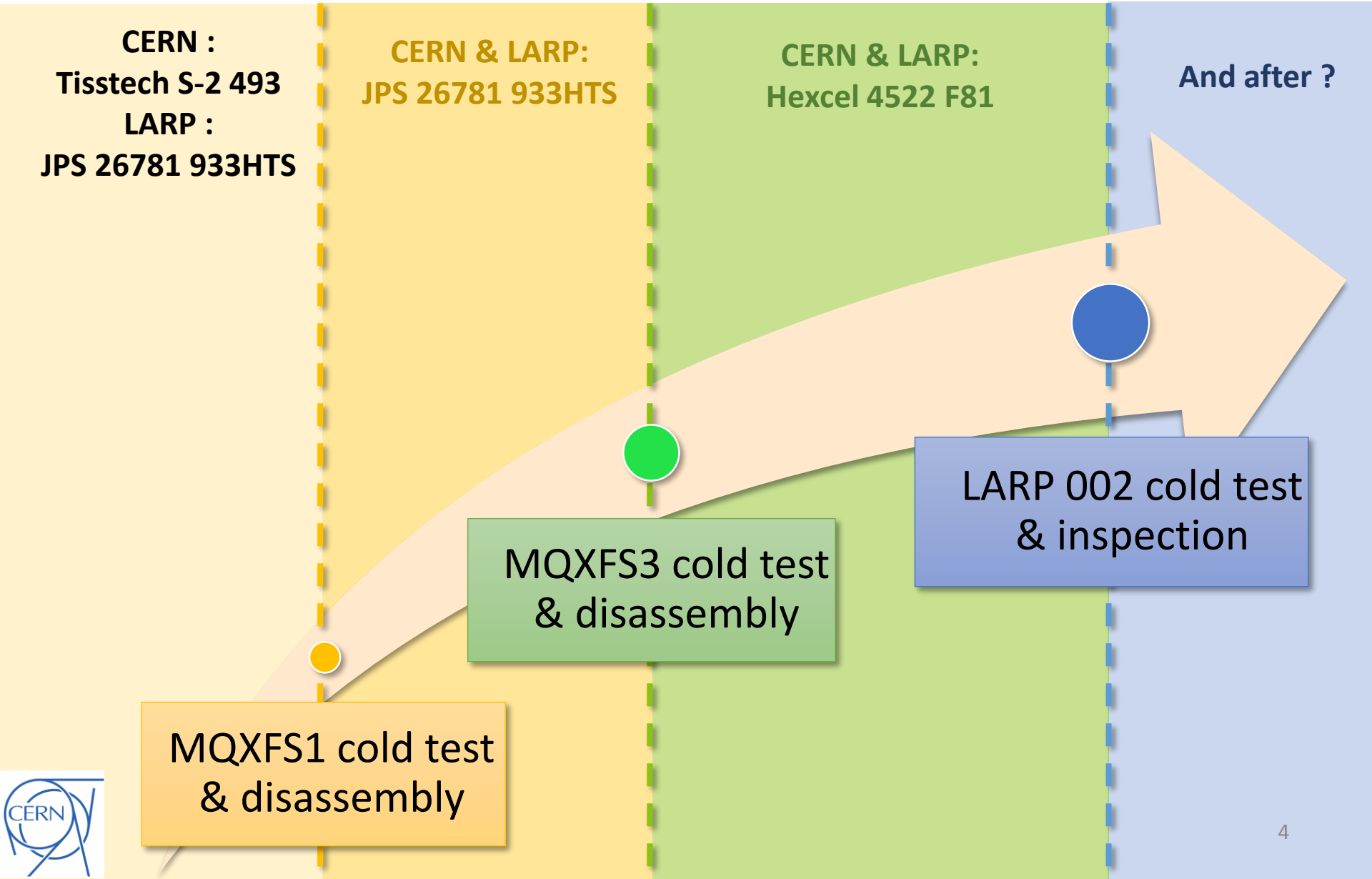
- Blistering and delamination of glass fibre layer at quench heater location
- Several levels of delamination depending on coils

How to address the issue ?

- Identify what type of glass fibre was used as inner impregnation layer in each coil
- Identify the exact location where delamination happens (type of interface)
- Assess influence of glass fibre properties on delamination : sizing, weaving pattern
- Design and perform peeling tests on impregnated glass fibre/QXF trace systems

Propose potential solutions, to be tested out in next CERN MQXFS coils

TIMELINE – INNER LAYER FABRICS USED AT CERN & LARP



STEP 1 - DISASSEMBLY OF MQXFS1

	Coil ref.	Inner layer fabric	Aspect of inner layer after quench training
CERN COILS	Coil #103 (1st gen)	Tissu de verre S-2 493 (Tisstech, FR)	  
CERN COILS	Coil #104 (1st gen)	Tissu de verre S-2 493 (Tisstech, FR)	  
LARP COILS	Coil #03	JPS 26781 933HTS (JPS, USA)	 
LARP COILS	Coil #05	JPS 26781 933HTS (JPS, USA)	 

Less blistering with JPS fibre ?

CONSEQUENCES OF MQXFS1 DISASSEMBLY

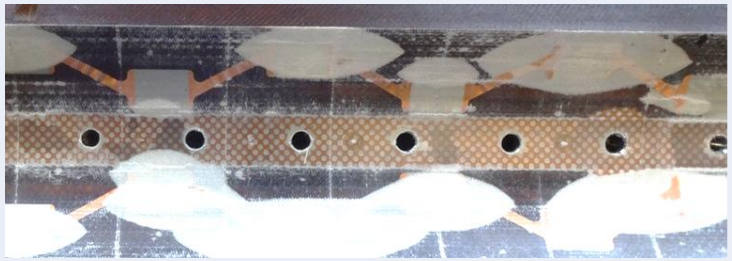
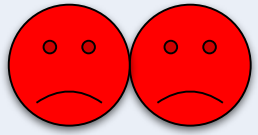
Problem might come from Tisstech glass fibre S-2 493

From 1st to 2nd MQXFS coils, change of inner layer fabric at CERN

CERN coils #200 to #206 impregnated with JPS fibre

- Much more blisters for CERN coils using this fibre
- Switch to JPS 26781 933HTS fibre at CERN

STEP 2 - DISASSEMBLY OF MQXFS3

	Coil ref.	Inner layer fabric	Aspect of inner layer after quench training
CERN COILS	Coil 105 (1st gen)	Tissu de verre S-2 493 (Tisstech, FR)	Photos non available – much fewer bubbles than for LARP 007 
	Coil 106 (1st gen)	Tissu de verre S-2 493 (Tisstech, FR)	
	Coil 107 (1st gen)	Tissu de verre S-2 493 (Tisstech, FR)	
LARP COILS	Coil #007	JPS 26781 933HTS (JPS, USA)	  

CONSEQUENCES OF MQXFS3 DISASSEMBLY

More delamination on LARP coil, impregnated with JPS fibre !

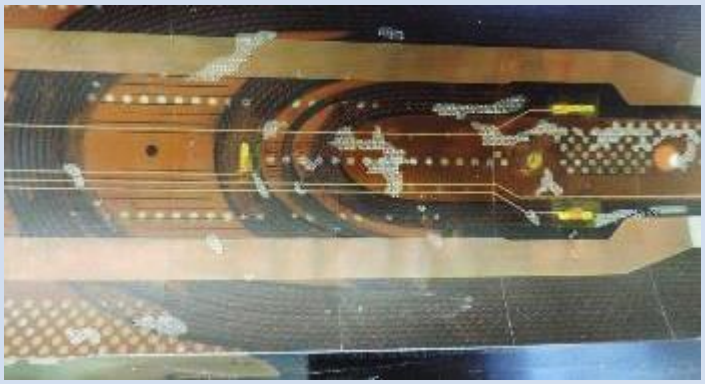
LARP suggestion: change inner layer fabric again, in CERN and LARP coils

CERN coils from #207 + LARP coils from #002 impregnated with Hexcel fabric

- Exact opposite situation as for MQXFS1

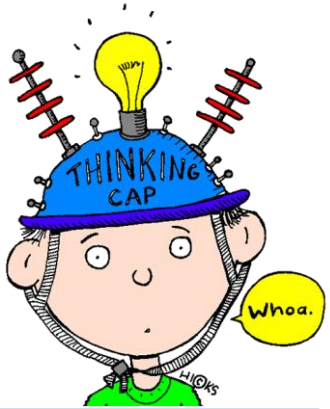
- Switch to Hexcel 4522 F81
- “more open” fibre weave → easier escape for helium bubbles during quenches ?

STEP 3 - INSPECTION OF LARP #002 BEFORE & AFTER MIRROR TEST

Coil ref.	Inner layer fabric	Aspect of inner layer
Coil LARP #002	Hexcel 4522 F81 (Hexcel, USA)	 After impregnation Dry zones  After cold powering Blisters only at QH location

The resin looks blurred, which is not usual
→ contamination by release agent ? → might explain the dry zones
→ poor quality of the photos ?

WHAT WE HAVE LEARNT FROM MAGNET DISASSEMBLY & WAY FORWARD



The influence of fibre type on delamination is unclear

- Type of sizing ?
- Weaving pattern (more or less open) ?

Need to understand better the delamination mechanism

- Nature of the interface where blistering occurs

→ Peel-off tests on impregnated “fibre + QXF trace” systems

- 1 layer of glass fibre fabric (100 µm) + 1 layer of QXF trace (150 µm)
- Impregnation with CTD 101K and curing at the Polymer Lab (TE-MSC-MDT)
- Peel-off tests at EN-MME-MM

PRINCIPLE OF PEELING TESTS

Single-cavity mould (cavity depth = h) + Shim (h – 250 µm)

1 layer spare QXF trace, laser-cut

Teflon paper strips on both ends

1 layer glass fibre, laser-cut

Shim + mould lid

Impregnation with CTD 101K + curing

15-mm strips

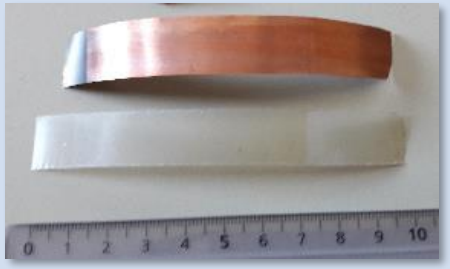
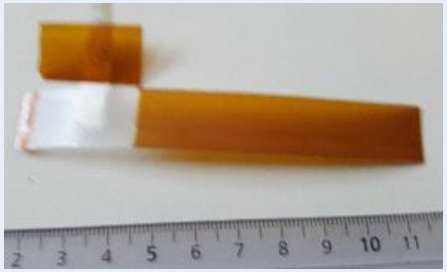
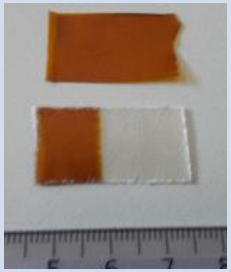
Metal/impregnated fibre

Polyimide/impregnated fibre

Peel-off tests 90 & 180°

UTS tensile machine
1KN load, 7mm/min

TEST 1 QXF TRACE + JPS 26781 933HTS

SAMPLE TYPE	TEST	LOAD (N)	ASPECT AFTER TEST	COMMENT
Metal/ impregnated fibre	90°	**0.58**		**NO ADHESION** between metal from trace (copper or inox) and impregnated JPS fibre
Polyimide/ impregnated fibre	90°	>21.5 Polyimide broke		**VERY GOOD ADHESION** between polyimide from trace and impregnated JPS fibre → Polyimide ripped before being peeled off !
Polyimide/ impregnated fibre	180°	>20.2 Polyimide broke		

TEST 1 QXF TRACE + JPS 26781 933HTS

1st HYPOTHESIS

Delamination occurs at metal/epoxy resin interface,
due to very bad adhesion of epoxy on metals

→ Confirmed by microscope observation of delaminated sample

which leads to…

2nd HYPOTHESIS

Glass fibre type should have little to no influence here

→ Need to confirm by doing another test with Hexcel 4522 F81 fabric

TEST 2 QXF TRACE + HEXCEL 4522 F81

SAMPLE TYPE	TEST	LOAD (N)	ASPECT AFTER TEST	COMMENT
Metal/ impregnated fibre	90°	**0.79**		**NO ADHESION** between metal from trace (copper or inox) and impregnated Hexcel fibre
Polyimide/ impregnated fibre	90°	19.34 Polyimide broke		**VERY GOOD ADHESION** between polyimide from trace and impregnated Hexcel fibre → Polyimide ripped before being peeled off !

Delamination also occurs at metal/epoxy interface, due to very bad adhesion of epoxy on metals

→ Confirms **2nd HYPOTHESIS**

i.e. glass fibre type probably has little to no influence on delamination

2 TYPES OF POTENTIAL SOLUTIONS

Increase epoxy/metal adhesion by treating metal

- Sanding the metal to make it rougher → already being done ✗
- Applying an epoxy primer to the metal ?
  - might blend with impregnation resin and cause problems
  - no products identified on the market

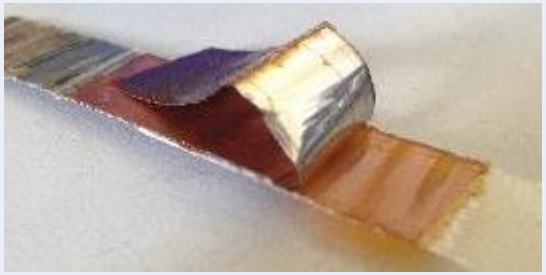
Suppress epoxy/metal interface

- Encapsulating the trace between two polyimide sheets ✓

→ needs to perform 3rd test

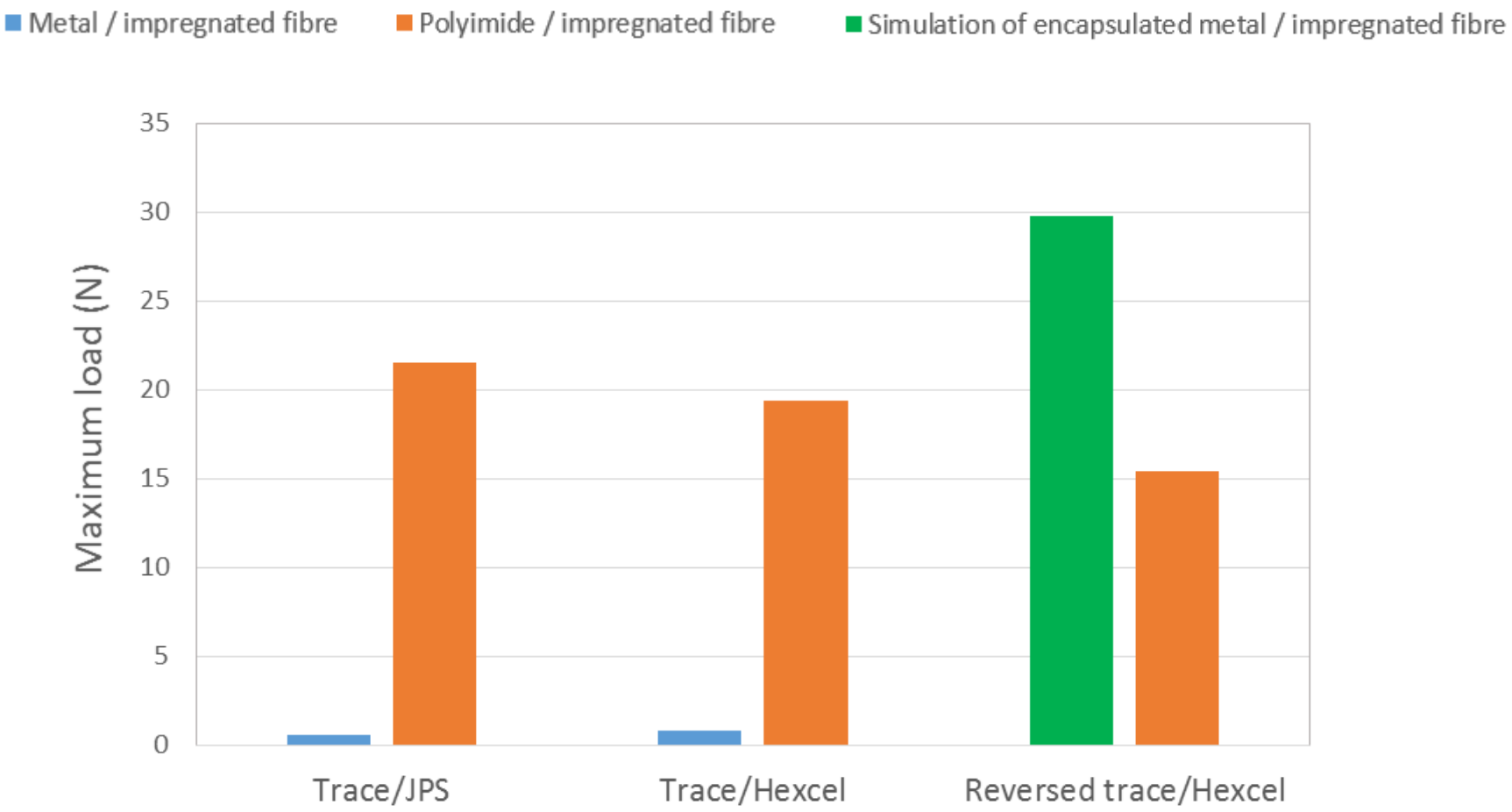
→ Simulation of encapsulated fibre:
Hexcel 4522 fibre + REVERSED trace

TEST 3 REVERSED QXF TRACE + HEXCEL 4522 F81

SAMPLE TYPE	TEST	LOAD (N)	ASPECT AFTER TEST	COMMENT
Polyimide/ impregnated fibre	90°	15.4 Polyimide broke	*similar to tests 1 and 2*	
Simulation of encapsulated metal/ impregnated fibre *(repeated 2 times)*	90°	29.8* Polyimide broke		**VERY GOOD ADHESION** between polyimide-"encapsulated" metal and resin Polyimide separated from metal and then ripped before being separated from resin !

*average of 2 values

SUMMARY OF RESULTS FROM TESTS 1,2 & 3



CONCLUSION

1

Encapsulating next MQXFS traces by adding a thin layer of polyimide on top

2

- To retrieve lost space, try to find new glass fibre fabric with smaller thickness
- With similar sizing as Hexcel 4522 F81