

TEST PROGRAM ON MODULE ADHESIVE INTERFACES

0. Scope of the tests

The scope of the test plan is to identify the baseline adhesives to bond the flex circuit on sensor and the module on supports meeting given requirements.

1. Definitions

MS adhesive: adhesive to connect the module to support

KS adhesive: adhesive to bond the flex circuit on sensor

2. Requirements

Adhesive MS:

1. MS1: keep the module aligned on support (preferably avoiding UV tags)
2. MS2: guarantee an efficient and reliable heat transfer from module to support
3. MS3: allow for module removal without any damage to the support surface

Adhesive KS:

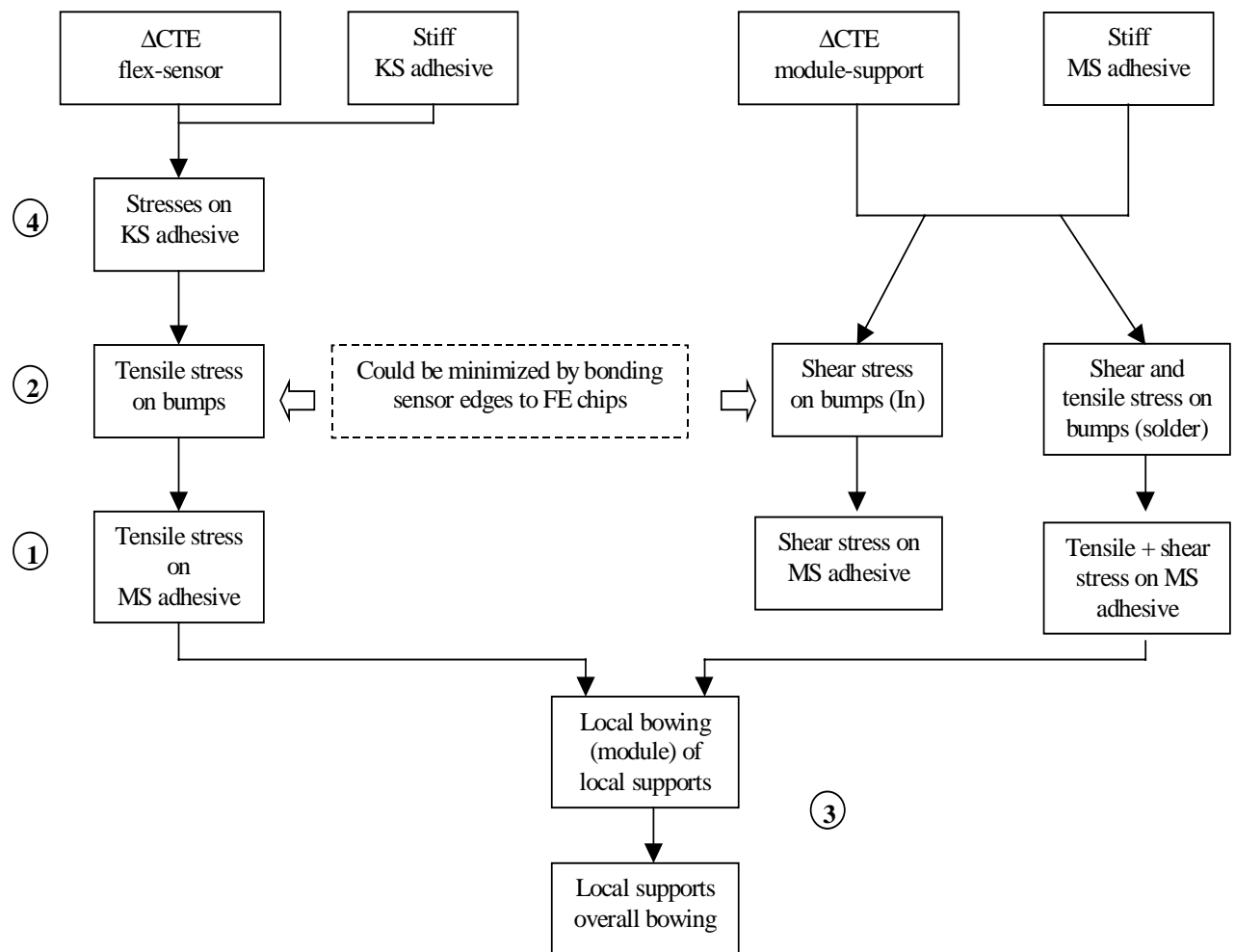
5. KS1: keep the flex circuit attached to sensor
 6. KS2: keep the flex circuit aligned relative to FE chips
- Adhesive MS and KS:*
8. MKS1: minimise stresses on bumps (module weakest point)
 9. MKS2: minimise local support distortions

3. Stress conditions

Cool-down stresses on module are due to unavoidable CTE mismatches between different materials across the bonded interfaces.

Stresses are proportional to the adhesive induced coupling (adhesive stiffness).

The following chart summarises the effects of CTE mismatches and adhesive coupling on module/local support stress conditions.



Due to differences in design the local support bowing is relevant only for the stave and negligible for the disk sectors.

The softer the adhesives the smaller the stresses.

In principle one should try to use the softest available adhesives, but if this is an advantage from the stresses and distortions point of view, it is a disadvantage from other point of views.

The following table identifies the requirements in terms of stiffness of the adhesives as function of the expected performances.

SPEC	EXPECTED PERFORMANCE	STIFF ADHESIVE	SOFT ADHESIVE
MS1	Keep module aligned on supports	*	
MS2	Efficient and reliable module to support heat transfer	*	
MS3	Allow module removal		*
KS1	Keep flex attached on sensor	*	
KS2	Keep flex aligned relative to FE chips	*	
MKS1	Minimise stresses on bumps		*
MKS2	Minimise local supports distortions		*

The choice of the adhesives is therefore a result of a reasonable and acceptable compromise of the expected performances.

4. Tentative specification for module to support adhesive

Stave simulations have been showing that if the MS adhesive young modulus is kept below 100 MPa the local (on module) and global (along the stave) distortions due to cool down should be less than 10 μm .

Therefore the limit of 100 MPa has been assumed tentatively as one of the specifications (MKS2) for the MS adhesive selection.

A second quantitative specification (MS2) is given by the max allowable temperature difference across the MS adhesive layer.

A 100 μm thick MS adhesive layer with a thermal conductivity 0.2 W/mK and 134 W uniform power produce a ΔT across the thickness of around 5 $^{\circ}\text{C}$ (assumed to be the max allowable).

To minimise the stresses on module and support during assembly room temperature curable adhesive are preferred.

The basic set of specifications for MS adhesive is given below:

- Thermal conductivity: $> 0.2 \text{ W/mK}$
- Young modulus: $< 100 \text{ N/mm}^2$
- Radiation hard
- Electrically non conductive
- Curing at room temperature
- Not flowing during application
- not creeping after curing
- Allow module replacement without damaging the support

5. Selection of enveloping cases

Potentially there are many possible combinations of conditions to be studied to select and qualify the KS and MS adhesive baselines.

In order to simplify the approach the following enveloping cases have been identified (ordered according to priorities):

1. Study and qualification of **MS adhesive interface**: assume rigid KS adhesive (max stress due to ΔCTE flex-sensor), neglect bumps flexibility (bare module assumed to be a rigid block of silicon)
2. Study of **actions on bumps**: assume rigid KS adhesive interface
3. Study of **distortions on local supports** (to be performed on stave only): assume rigid KS adhesive interface, infinite rigidity of bumps, stiffest MS adhesive among those selected
4. Study and qualification of **KS adhesive interface**: assume bare module to be infinitely rigid (rigid MS adhesive, rigid bumps).

Tasks 1, 2, 4 can be carried out assuming, conservatively, the local supports to have locally (on the module area) an infinite rigidity: small (negligible) module out-of-plane compared to the overall distortions.

Task 3 is just a crosscheck of the calculations done so far.

KS interface is less critical than MS one: KS adhesive requirements are less severe. Therefore initially task 4 won't be detailed and all efforts will be focused on task 1 and 2, which will allow to select the MS adhesive.

6. Glue deposition and module mounting techniques

The glue deposition and module mounting are of course the most critical issue affecting the quality and reliability of the module bonding.

It is not possible to specify any tentative protocol for that, as the successful methodology is the result of a good combination of capabilities and techniques.

The assessment of the glue deposition and module mounting process has also to address the identification of the procedures to avoid any contamination of bump volume due to MS adhesive penetration in between the FE chips gaps (the adhesive layer should break along the FE chip inner boundaries).

A suitable process will be selected among those assessed by the institutes during the present test plan activities.

The adopted process has to be documented in order to be reproducible by any assembly site.

7. Test setups

Five test setups are basically necessary to develop the test plan:

1. Graphite block (65x25x10 mm³) with dummy silicon heater (60x20x0,65 mm) bonded on with 100 µm MS adhesive layer (see fig. 1)
2. Sandwich structure (C-C support + MS adhesive + glass die, see fig. 2)
3. Sandwich structure (C-C support + MS adhesive + dummy silicon + KS adhesive (rigid epoxy) + kapton, see fig. 3)
4. Sandwich structure (C-C support + MS adhesive + dummy bare module + KS adhesive (rigid epoxy) + kapton, see fig. 4)
5. Stave with 13 dummy silicon heaters (kapton on) bonded with selected adhesive

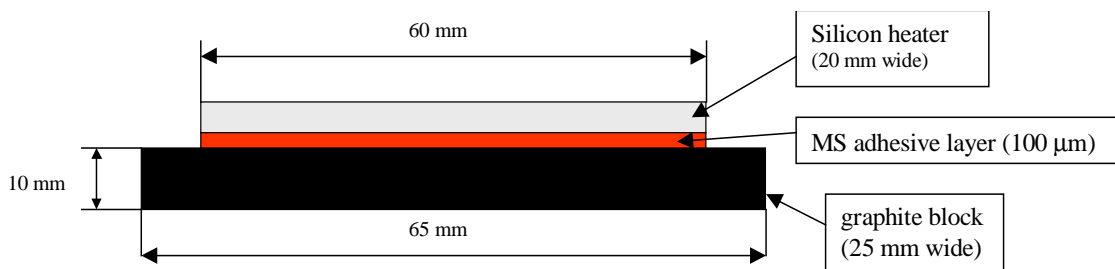


Fig. 1: setup n°1

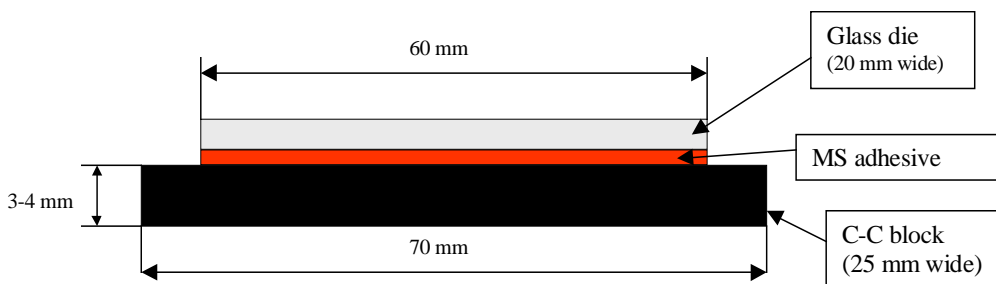
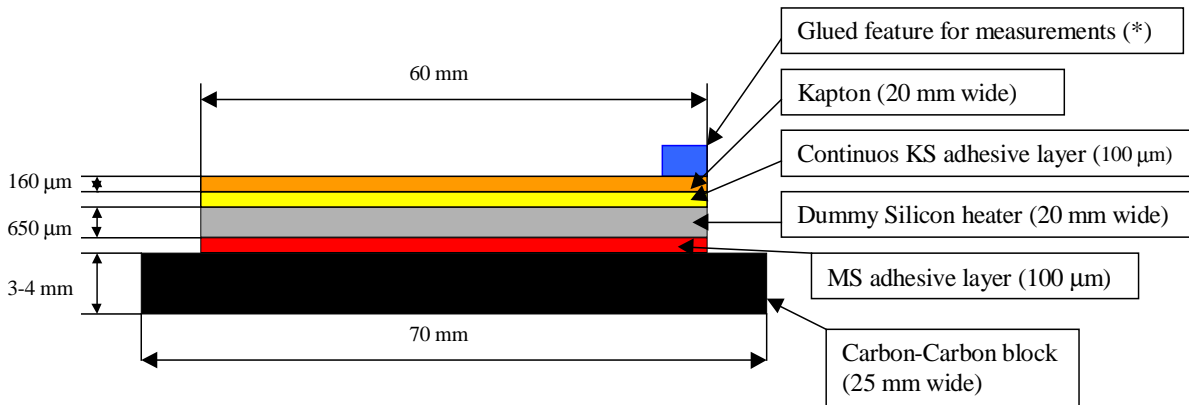


Fig. 2: setup n°2



(* bonded directly on dummy silicon through an opening on kapton

Fig. 3: setup n°3

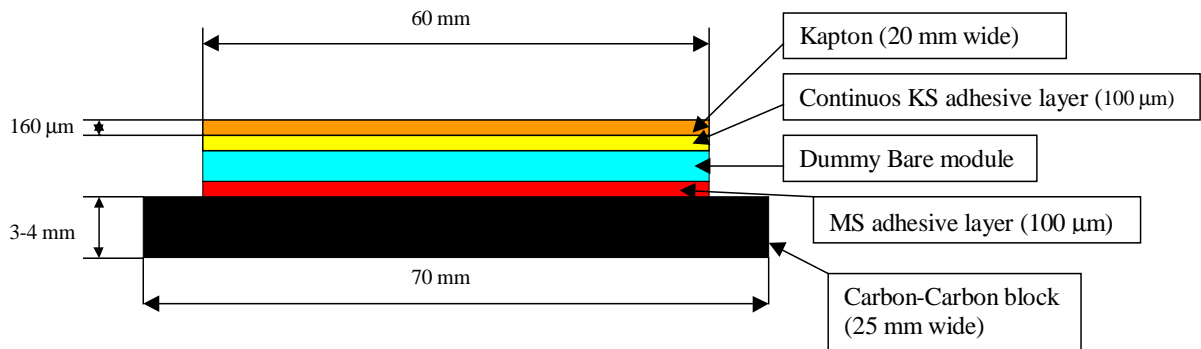


Fig. 4: setup n°4

8. Test protocols

- A. adhesive applicability test
- B. module removability test
- C. thermal conductivity measurement
- D. shear modulus measurement
- E. creep test (check position stability)
- F. thermal contact reliability test
- G. peeling test (check adhesive bonding properties)
- H. bump connectivity test
- I. stave stability test

8.1 Adhesive applicability and module removability tests (A+B)

These two tests can be done in combination on test setup type 2.

The glass being transparent is suitable to check if the mounting technique is good or not (air trapping).

The adhesive will be laid using masks with different thickness: 50-75-100 μm. The mask has to be shaped in order to keep the adhesive away from the gap region between the chips.

The adhesive is considered applicable at a given thickness if a uniform and continuous layer can be achieved, over each chip bonding area and the adhesive is confined inside each single chip area itself

After glass mounting with the suitable technique (to be investigated) and curing (could be required to speed up the test), the removability test can be done.

I think that, especially for stiffer adhesives, it will be not possible to use any automated technique (lifting vacuum chuck) to remove the module, since the required force would be too high for the light support structure, much higher than the design loads.

I believe that a manual technique (cutter blade) has to be developed in particular for the stove, whose constraints of the layout in z are very binding.

The adhesive is considered to allow module removability if the glass can be removed (even broken) relatively easily (no heavy load applied) and the C-C surface can be cleaned from the residual adhesive without any relevant damage (scratches, abrasions..)

8.2 Thermal conductivity measurement (C)

Test performed on test setup type 1.

Immerse the graphite basement in a thermostatic bath keeping the temperature around 5 °C below the room temperature (minimise the heat dissipated by convection to the ambient).

Apply 8 W power load on the heater.

Measure the average temperature on silicon surface (using a IR camera).

Calculate the ΔT across the adhesive layer (equal to ΔT bath-silicon surface, as the thermal impedance of the graphite block and of silicon is negligible compared to that of adhesive layer) and hence calculate the thermal conductivity.

A temperature cross check with PT100 (or similar) will have to be implemented.

This test could also be used as a cross-check of the adhesive joint quality. If the temperature on the silicon is uniform to less than 1 °C then the joint is good.

8.3 Shear modulus measurement + creep test (D+E)

These tests are performed together on the same setup.

Setup type 3 is used.

The setup is fixed on a support, an in plane force F is applied on the block, along z direction (length).

The in plane displacement is measured as function of the applied force F .

The stress/strain curve is determined (in the elastic range): shear modulus measurement.

Then a constant force (in the adhesive elastic range: 100-200 g) is applied for 24 hours monitoring if any creep occur (creep test).

8.4 Thermal contact reliability test (F)

Test performed on setup type 3.

The setup is thermal cycled from + 30 °C to – 30 °C, with the max allowable frequency.

At regular time intervals (every 20 cycles), the setup bottom surface is put in contact with a thermostatic bath liquid surface at a temperature around +10°C (ΔT across 5 mm of C-C with 4 W/mK thermal conductivity is around 10°C so that the silicon surface should stay around 20°C).

The power on heater is switched on (8W) and the temperature distribution on the top surface of kapton is recorded (thermocamera picture).

The different pictures are then compared to see if there is a progressive depletion of the adhesive thermal coupling efficiency (hot spots).

8.5 Peeling test (check adhesive bonding properties) (G)

Test performed on setup type 3.

The setup is fixed horizontally on a tensile test tool.

A force F (perpendicular to the setup surface) is applied on the testing feature (but preventing any moment on the silicon).

The stress/strain curve is determined up to delamination.

8.6 Bump connectivity test (H)

This test assume that the bumped joint strength has been already addressed and that a solution to prevent mechanical fracture of the bumps due to tensile stress has been already identified (see tests performed by Genoa)

Test performed on setup type 4.

The setup is thermally cycled from + 30 °C to – 30 °C, with the max allowable frequency.

At regular time intervals (every 20 cycles), the bump connectivity is checked (how?) to see if any progressive damage occurs.

The test should be repeated on irradiated samples.

8.7 Stave stability test (I)

Test performed on setup type 5.

The setup is prepared using selected stiff glue (the stiffest one among the selected candidate to maximise the module to stave coupling).

The stave is supported on 3 points using the available tools (cold box).

The stave profile along the centreline is measured at room temperature and at –10 °C.

The two profiles are then compared to evaluate the differential deflection due to module-support compling.

9. Test sequence and number of setup required

The plan will start focusing on the MS adhesive selection.

The test program for MS interface qualification can be split into four sequential steps corresponding to different selection stages:

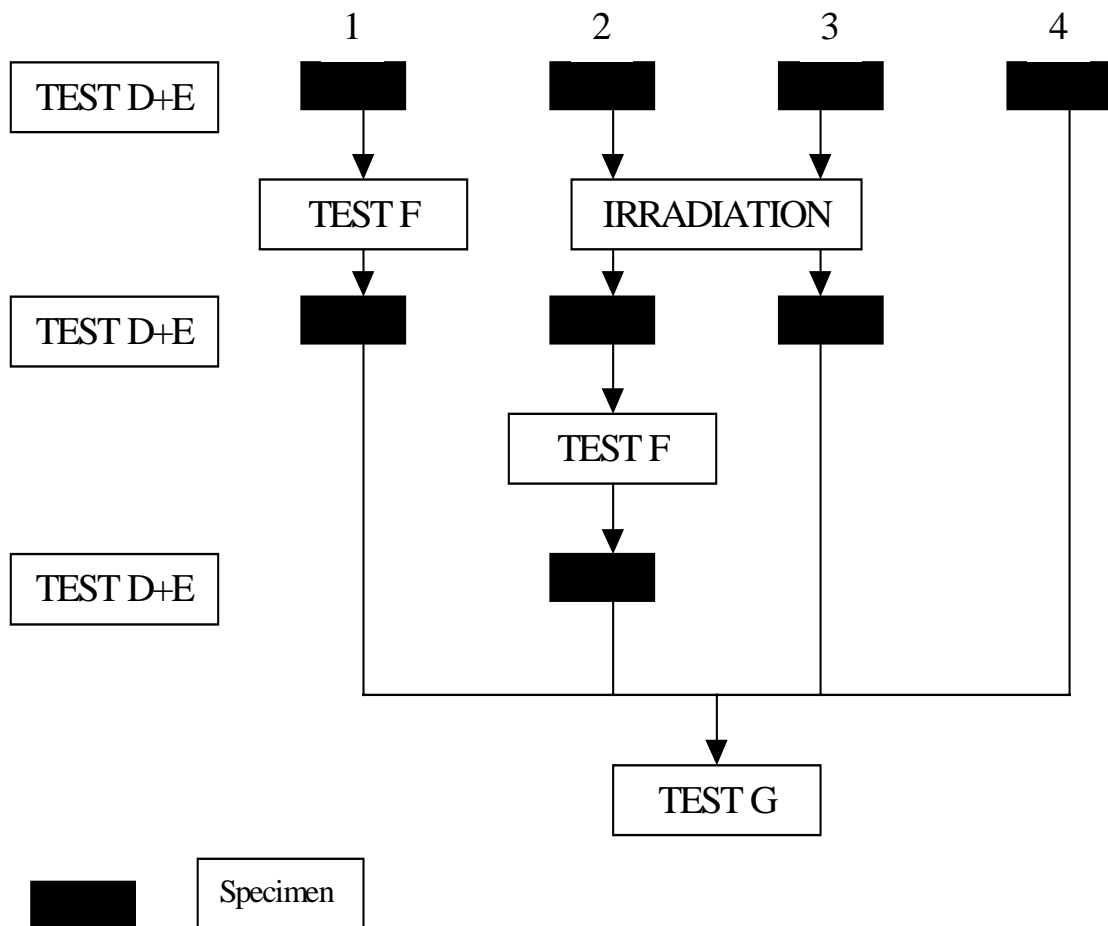
1. first selection level (all candidates):
 - 1.1.test A and B + basic shear and creep tests
 - 1.2.test C
1. second selection level (on candidates selected by step 1): test D+E+F+G
2. third selection level (on candidates selected by step 2): test H
3. fourth selection level (on stiffest selected adhesive by step 3): test I

The basic shear and creep tests are meant to provide the first feeling on the adhesive performance. They can be performed using simple techniques (not necessarily those used for tests D+E) just to check if the adhesive has enough strength and does not creep.

All labs should be involved at least in the preparation of setup 2,3 and in test A, B and basic shear/creep test to collect the widest possible experience on the bonding process.

Tests D, E, F, G of the second selection step, are the most critical and time consuming ones.

They all should be carried out in the same Lab according to the following scheme.



At least 4 specimens for each adhesive will be required.
 All 4 specimens will be subject to an initial thermal test (with the IR camera) to check the as built quality of the MS interface.

The following table identifies for each selection level the related tasks, the setup type, the quantity of specimens and the involved institute:

SELECTION LEVEL	TASKS	SETUP TYPE	N° of specimens per adhesive	LAB
1.1	Specimen preparation	2	As many as convenient	all
1.1	Tests A+B+ basic shear/creep	2		all
1.2	Specimen preparation	1	1	Bonn-CPPM
1.2	Test C	1		Bonn-CPPM
2	Specimen preparation	3	4	all
2	Tests D+E+F+G	3		Bonn-CPPM-Genoa
2	irradiation	3		LBNL (CERN?)
3	Specimen preparation	4	2+2(for irradiation) per bump type	Genoa-Bonn
3	Test H	4		Genoa-Bonn
3	irradiation	4		LBNL (CERN?)
4	Stave preparation	5	1 (only one test with stiffest adhesive)	Genoa
4	Test I	5		CPPM-Genoa

10. Material procurement

Carbon-Carbon

We can use a lower transverse thermal conductivity material (cheaper and available on stock at least at SGL).

Typical properties of standard SGL C-C (SIGRABOND 1501 G):

- bulk density 1.45-1.49 g/cm³
- thermal conductivity, parallel 23 W/m K
- thermal conductivity, orthogonal 4 W/m K
- CTE, parallel -0.8×10^{-6} 1/K
- CTE, orthogonal 7×10^{-6} 1/K

The C-C can be impregnated only on surface by means of a simplified procedure and then machined flat.

Procured and prepared by: Genoa (delivered this week)

Quantity= 50

Prepared by:

Dummy Si heaters: 60 available in Genoa and Bonn

Dummy bare modules:

Quantity:

- *In=* 4* n° of adhesive to be tested
- *Solder=* 4* n° of adhesive to be tested

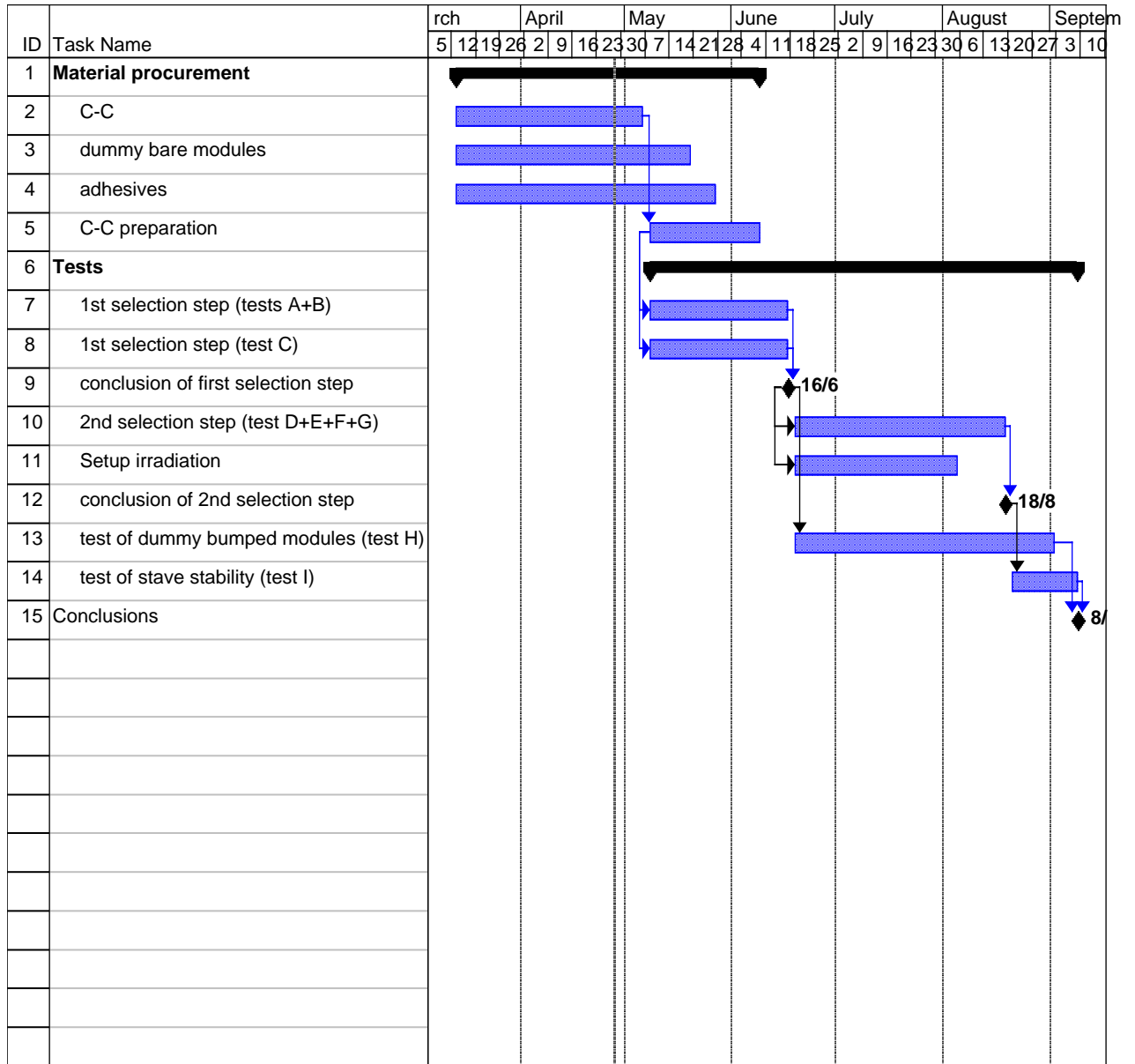
Available by:

Graphite blocks: 20 available in Bonn

Adhesive

See candidate table

11. Planning



12. Test data and specimen labelling

Every specimen prepared and tested has to be labeled and a corresponding data sheet has to be filled in with all relevant data qualifying the process and collected test data.

IR camera pictures should be recorded as well.

13. Adhesive candidate list

Here after a list of the potential candidates collected up to now on the basis of information coming from past experience, vendors, and other sources.

The list will be subject to a few additions/modifications.

Even if it is a long list, I'm pretty sure that after the first selection step the number of candidates will reduce by a factor of 2-3.

Anyway, the number of candidates for the second selection step should be limited to 8.

Therefore I think it is worth to start with a relative big number of candidates given the difficulty to find candidates satisfactorily meeting all the requirements.

VENDOR	PRODUCT	TYPE	HARDNESS	VISCOSITY (cPs)	THERMAL CONDUCTIVITY (W/mK)
EPOTEK	T905	epoxy	81 (shore D)	6000-13000	0.7
EPOTEK	T7110			3000	1.25
MASTER BOND	MasterSil 705TC	silicon	50 (shore A)	paste	1.88
MASTER BOND	EP37-3FLFAO	epoxy		18000-22000	1.25
MASTER BOND	EP21TDC2AO	epoxy		paste	1.25
MASTER BOND	EP21TDCANHT	epoxy		paste	3.125
MASTER BOND	EP21ANHT	epoxy		paste	2.875
THERMAGON	T-gon 415-10A	silicon			0.23
DR. NEUMANN PELTIER-TECHNIK	NE001	silicon			0.24
POLYTEC	NuSil Technology R-2930	RTV silicon	80 (shore A)		3.7
EMERSON-CUMING	STYCAST 4954	RTV silicon rubber	40-60 (shore A)	4000-6000	1.3
EMERSON-CUMING	ECCOBOND 45	epoxy	60-70 (shore D)		0.2 ?
DOW CORNING	Q3-6093	silicon	45 (shore A)	nonflow	0.31