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Specification, production and quality control for the straw tubes of the outer tracking system

Sebastian Bachmann
Physikalisches Institut, University of Heidelberg, Germany

Abstract

Straw tube detectors used for the LHCb outer tracking system are described. Specifications for the production are given and the quality control strategy is explained.

1 Specification of the straw tubes

For the LHCb outer tracking system approximately 150km of straw tubes have to be produced. The production will be done by Lamina dielectrics[1]. The straw tubes are winded from two foils, the inner foil is made of 40 μm thick Kapton-160/XC/370, subsequently denoted as Kapton-XC layer. The outer foil consists of a laminate of 25 μm thick Kapton-100/XC/10e7 and 12.5μm aluminium, subsequently denoted as laminate. Kapton-XC is a carbon doped Kapton foil, resulting in an electrical conductivity. Kapton-160/XC/370 and Kapton-100/XC/10e7 differ in the thickness and the concentration of the doping. Their properties are shown in table 1. Kapton products are delivered by DuPont[2]. The Kapton/Aluminium laminate is produced by GTS[3].
The assembly of straw tubes foreseen for the usage in the LHCb experiment is shown in figure 1. To guarantee their reliable operation they have to fulfill stringent requirements. They concern the mechanical and electrical properties of the straws. Gas tightness of the straws is another important issue. Finally the contamination of the straw tubes by dust or any residuals must be avoided during the production, curing, packaging and transport of the straw tubes.
The specification of mechanical and electrical properties, as well as those for the gas tightness of the straws are listed in table 2.

[1]Lamina Dielectrics Ltd, Myrtle Lane, Billingshurst, Sussex, RH14 9SG, England
[2]DuPont High Performance materials, U.S.Rt.23 & DuPontRoad, Circleville, OH 43113
[3]GTS flexible materials Ltd, 41 Rassau IndustialEstate, Ebbw Vale, Gwent, NP23 5SD

Material	Thickness	Surface resistivity	Bulk resistivity
Kapton-160XC/370	40 μm	370 $\Omega/\square$	0.94 Ωcm
Kapton-100XC/10e7	25 μm	$10^{7\pm2}$ $\Omega/\square$	$2.5 \cdot 10^{4\pm2}$ Ωcm
Aluminium	12.5 μm	$\div$	$3.2 \cdot 10^{-6}$ Ωcm

Table 1: Properties of raw materials for straw tubes

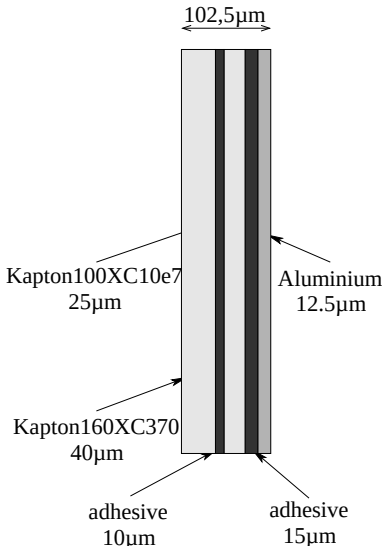

Figure 1: Assembly of straw tubes.

2 Production of straw tubes

The preparation of the raw materials, the winding of the straws, curing and packaging takes place in a clean room. First, the incoming raw material is slit down to strips of 9.5 ± 0.1 mm wide strips. During slitting the raw materials are optically inspected for damages and cleanness of the surface. Special care is taken to guarantee the cleanness and quality of the blades used for slitting. During the whole production it is guaranteed that the raw materials as well as the final product is touched only using gloves to avoid any contamination of the detectors by residual grease.
The next step is the winding of the straw tubes. One strip of each material is wound with an overlap of half the strip size on a mandrel, forming a tubular section. Each foil is covered with an approx. 5μm thick layer of adhesive. It is applied by an automatic vacuum mixing and dosage system. The adhesive used has been tested for outgassing and radiation hardness. During production an additional inner protective mylar foil is simultaneously wound on the mandrel inside the straws. The inner side of the mylar is lubricated by stearic and liquid, carbon based lubricant. These materials are not in contact with the straw tubes. Despite that, it has been validated in ageing tests that there is no impact on the radiation hardness of the detectors by these materials.
The production of the tubes is endless, they are cut by means of scissors to

the appropriate length. They are stored in sealed Correx boxes, each box containing a silica gel pack. Before shipping the straws to the institutes the Correx boxes are firmly pacek in wooden cases.

3 Quality control

The quality of the straw tubes is controlled at every step of the production. Namely there are quality controls

- of the incoming raw materials.
- by the operator during the slitting of the raw materials and the winding of the straws.
- by the Lamina inspection office of straw tube samples taken directly from the production line.
- by the Lamina inspection office after curing of the adhesive.
- at the institutes after delivery.

To guarantee the quality of the final product general requirements for the production are the following:

- Glue, mylar foil, lubricant, tools and production machines used are according to Lamina specification.
- Raw materials and tools in contact with the raw materials must not be touched by bare hands, wearing vinyl gloves is mandatory.
- Slitting, winding and curing of the straw tubes takes place at Lamina clean room.
- temparature and humidity of the production site is during the entire prodution within the specifications given in table 3 and logged.
- The operators and inspectors follow the instruction of the Lamina quality control plan.
- All information is recorded on the straw tube production log sheet.

3.1 Control of incoming raw materials

The Kapton-XC layer and the laminate will be delivered in several batches. The beginning and the end of each batch is investigated by Lamina. The thickness of the material and its resistivity will be measured. The devices to perform these measurements are delivered by the institutes. The batches are only accepted for the straw tube production if the samples fulfill all tolerances from table 4. The samples are sent together with the test results to the institues to check the results.

3.2 Tests by operator during slitting of raw materials

The main issues to be verified during slitting of the raw materials is the cleanness of the blades and the rollers. They are checked hourly for deposits. The quality of blades is examined every 4 hours. Surfaces of the raw materials are regulary observed for damages, dust or deposits.

3.3 Tests by operator during winding of straw tubes

The winders is thoroughly cleaned and decontaminated before using. It must be guaranteed that the raw materials as well as the final product is not contaminated. The adhesive is mixed by means of an automatic vacuum mixing and dosage system. The tension of the foils during winding is controlled by an automatic tensometer.
During the production the operator takes every 15 minutes a sample from the production, checking the following parameters to be within the specifications given in table 2:

- overlap of film strips
- inner spiral gap
- outer spiral gap
- inner diameter
- bond
- internal/external damage
- quality of adhesive

Additionaly all surfaces are checked frequently for deposits.

3.4 Tests by inspection office during production

The inspection office identifies samples of approximately 100 mm long straws. Pitch, inner and outer spiral gap and the inner diameter are also measured for these samples at higher accuracy. The surfaces are inspected for damages and a peel test is made to judge the quality of the gluing.
All test results are note down on the straw tube production log sheet. This sheet is made available to the institutes.

3.5 Tests by inspection office after curing

After two weeks, when the adhesive used for straw tube winding is cured, samples from the straw tubes additional tests are taken. They include a measurement of the tensile strength and the bond strength. Further the straightness of the straw tubes is measured. The results are logged on the straw tube prodduction log sheet. Straw tube batches meeting all criteria are released to be sent to the institues.

3.6 Batch control and logging

It is crucial to identify sources of problems possibly appearing at any stage of the production and commisioning of the straw tube modules. Therefore a strict logging of materials used, as well as all test results and ambient parameters is mandatory. Therefore the production of straw tubes is subdivided in batches of 270 straws, sufficient to build modules of 256 straws plus spare and few straws needed for tests. All straws within one batch are build from the same batches of raw materials. The straw tube production log sheet allows to trace back the batch number of all materials used for a specific batch of straws. Samples of raw materials from every batch are made available to the institutes.
As already described in the previous section also all test results from raw materials, and those tests performed during production and after curing are logged on the straw tube production log sheet. These sheets are provided to the institutes as paper copies and as Excel worksheets.

Description	Specification	Test method	Remark
Inner diameter	$4.9^{+0.02}_{-0.0}$ mm	Taper gauge optical illuminator	Test of samples by Lamina during production
Wall thickness	$102.5 \pm 10\mu$m	Mikrometerschraube	Test of samples by Lamina during production
Length	2500 ± 5mm		
Deviation from straigtness	< 1 mm	to be defined	Test of samples by Lamina after curing
alternatively: Deviation from straigtness	< 1 mm	to be defined	Tested at institute after delivery
Width of film strips	9.5mm $\pm$ 0.1mm	Measure	Checked frequently by operator
Overlap of film strips	4.75 $\pm$ 0.95mm	eye glass	Test of samples by Lamina during production
Spiral gap (inner)	0.1 – 0.3 mm	eye glass	Test of samples by Lamina during production
Spiral gap (outer)	0.1 – 0.3 mm	eye glass	Test of samples by Lamina during production
Surface quality	no damages	optical	Test of samples by Lamina during production
Quality of adhesive	uniformly distributed	peel test/optical	Test of samples by Lamina during production
Tensile strength (???)	*Min. 70 N (???)*	Tensometer	Test of samples by Lamina after curing
Bond strength (???)	*Min. 50 N (???)*	Tensometer	Test of samples by Lamina after curing
electrical resistance (inner layer)	$< 300\,\Omega$	to be defined	Tested at institutes after delivery
electrical resistance (inside to outside)	depends on test method	to be defined	Tested at institutes after delivery
gas tightness	$< 0.5\frac{mbar}{min}$ at $\Delta p = 10$mbar	decay time of overpressure	Test of samples by Lamina after curing
alternatively: gas tightness	$< 0.5\frac{mbar}{min}$ at $\Delta p = 10$mbar	decay time of overpressure	Tested at institutes after delivery

Table 2: Specification of the straw tubes.

Parameter	Range
Temparature	$20 - 23°\mathrm{C}$
Relative humidity	$< 70\%$

Table 3: Specifications of ambient parameters for the production site.

Material	Thickness	Surface resistivity	Resistance
Kapton-160XC/370	$40\,\mu$m $\pm 4\,\mu$m	$< 500\,\Omega/\square$	$\div$
Lamiate	$53\,\mu$m $\pm 5\,\mu$m	on Kapton XC side $< 10^9\,\Omega/\square$	inside to outside t.b.a.

Table 4: Requirement specification for raw materials for straw tubes