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STUDY OF TENSILE RESPONSE OF KAPTON AND MYLAR STRIPS TO Ar AND CO_2 MIXTURES

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Abstract

Gas mixtures are known to affect mechanical properties of plastic materials of interest in HEP gas detectors. We have studied tensile properties of several materials for use in the straw tube detector of experiment BteV at the Fermilab Tevatron. A straw tube is a complex structure made up of two different layers of polymeric material with aluminium deposition and glue, therefore we have decoupled all these elements to better understand gas effect on each one. We have tested four different gas mixtures of Ar and CO_2 on several strips of kapton and mylar loaded at about 200g (typical tension for straw tubes in BTeV). We have also considered temperature, pressure and relative humidity effects on strips mechanical tension.

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1. PURPOSE

The purpose of this study is to test tensile response of 25μm-thick kapton and mylar strips in different states of gas composition. The study is motivated by the recent observation of dependence of straw tubes mechanical tension on gas composition (ref 1,2). A full understanding of such an effect is made difficult by the influence on straw tubes of environmental conditions, such as humidity and temperature. Besides, it is desirable to decouple the effect of gas composition among various straw tubes components (kapton, mylar, glue, coating). Therefore, we have set up an appropriate test apparatus to control humidity, pressure and temperature, which employs load cells with online readout; each load cell holds a single strip at a typical straw tube mechanical tension of ≈200g.

1. APPARATUS

The measurement is carried on inside a steel box (volume ≈60 l) (fig 1) with a perspex cap. On the two smaller sides of the box there are feedthroughs to insert cables and gas pipes. The box is thermally insulated by means of a polystyrene tank. Inside the box three strain gauges (ref 3, 4, 5) are located: two are loaded with strips, the third is empty and is used as a reference. The box also contains a temperature sensor (ref 6), a pressure sensor (ref 7) and a relative humidity sensor (ref 8) all connected to a Field Point computer readout system (ref 9). Box, acquisition system and a computer are inside a room kept at 22±2°C. Box temperature varies within 22±2°C and relative humidity within 0% and 1%. Two mass flowmeters (ref 10) are used to control gas mixture and pressure. Gas flux is made uniform by means of a diffuser.

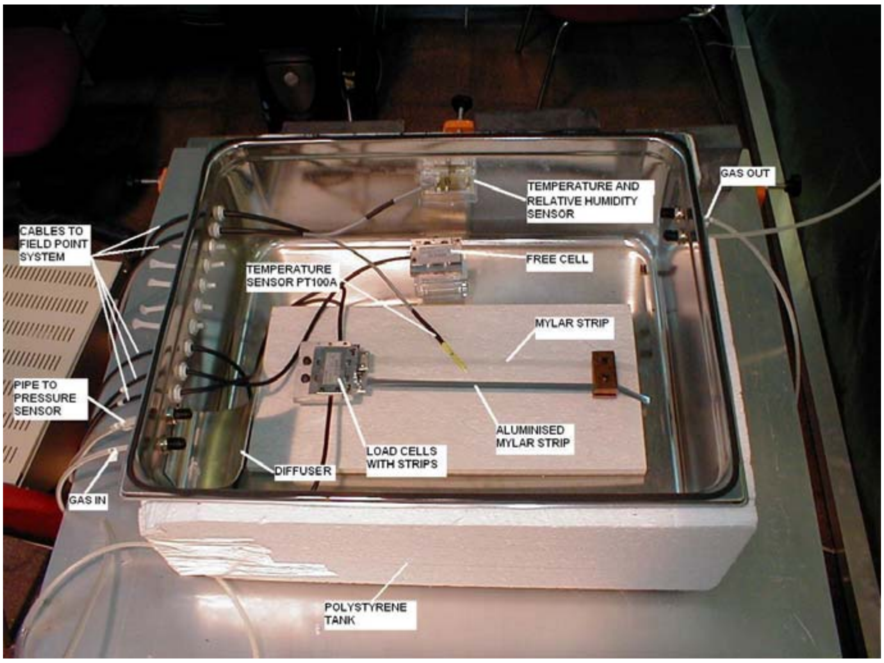

FIG. 1: Measurement apparatus.

2. MEASUREMENTS AND RESULTS

Six strips have been tested: kapton (strip A, ref 11), carbonated kapton (strip B, ref 12), carbonate aluminised kapton (strip C, ref 13), mylar (strip D, ref 14), aluminised mylar (strip E, ref 15) and aluminised mylar with glue traces (strip F, ref 16) obtained from an unrolled straw tube (ref 17, 18). Table 1 summarizes strips tested and their initial load.

TAB 1: Tested strips.

Strip	Identification letter	Thickness (µm)	Width (cm)	Length (cm)	Load (g)
Kapton	**A**	25±2	1	30	161.8±0.2
Carbonated kapton	**B**	25±2	1	30	177.9±0.2
Carbonated aluminised kapton	**C**	25±2	1	30	122.6 ±0.2
Mylar	**D**	12	1	30	201.9±0.2
Aluminised mylar	**E**	12	1	30	197.5±0.2
Aluminised mylar with glue	**F**	30	1.2	30	162.7±0.2

We have investigated effects of p, T, RH and tensile response to different percentage of CO_2 in a mixture with Ar. The effect of temperature is considerable, therefore we apply a T-correction to load cell values. Small p and RH changes are present during the phase of gas composition change, dedicated measurements were performed in order to assess their negligibility.

2.1 Temperature effect

Strips mechanical tension is strongly dependent on temperature; tensile response to temperature in different gas mixtures is used to obtain a corrective slope coefficient α to remove T influence on strain. Correction is in the form:

$$G' = G + \alpha \Delta T \tag{1}$$

where G represents strip tension (g), $\Delta T = T - T_0$ and $T_0 = 21°C$ taken as a reference temperature. α values in Ar and in CO_2 are shown in tab.2. Fig 2 shows an example of scatter plot tension vs temperature. Typical strips responses with and without T correction are shown in fig 3. We estimate the T correction effective within ±2g.

TAB 2: α values in Ar and in CO_2.

Strip	α (g/°C) in Ar	α (g/°C) in CO_2
Kapton A	-4.15±0.01	-3.29±0.01
Kapton carbonate B	-4.65±0.01	-2.89±0.01
Kapton carbonate aluminised C	-4.18±0.01	-3.12±0.01
Mylar D	-5.08±0.01	-3.94±0.01
Mylar aluminised E	-4.12±0.01	-3.36±0.01
Mylar aluminised F	-5.37±0.01	-5.39±0.01

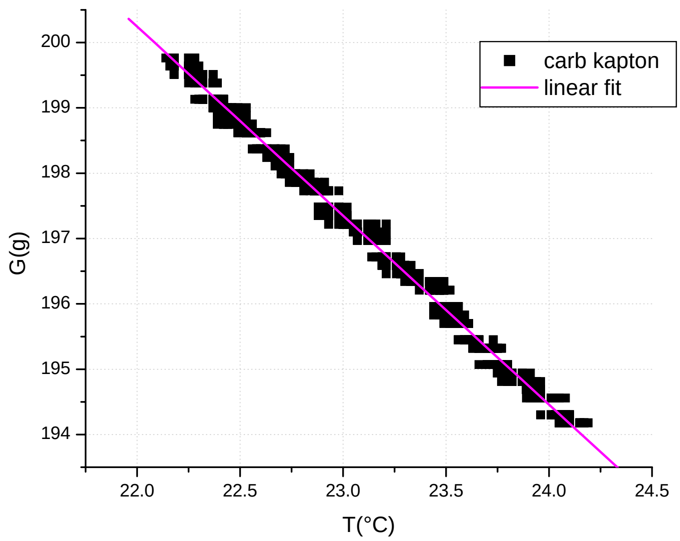

FIG. 2: Scatter plot example of tension vs temperature for carbonated kapton in CO_2.

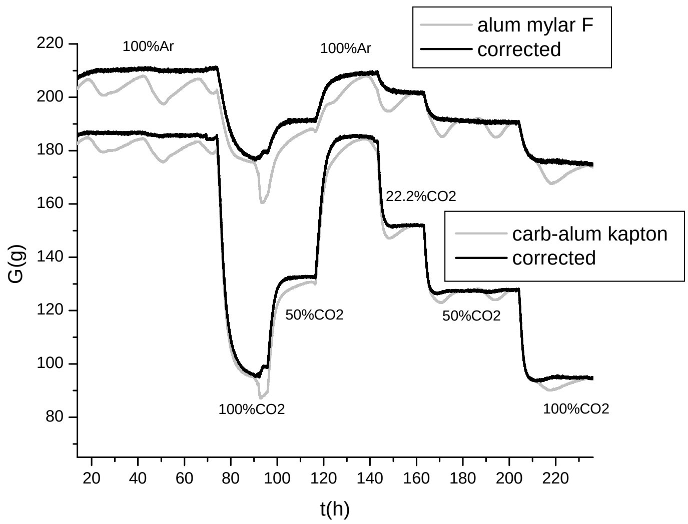

FIG. 3: T correction for aluminised mylar F and carbonated aluminised kapton in different Ar-CO_2 mixture.

2.2 Pressure effect

To study pressure effect on the strips we produce a quick pressure variation by changing flow rate; in this way T is constant and RH changes less than ±0.5%. Fig 4 and 5 show the effect on p, T, RH, on the two strips and on the free cell when pressure is rapidly increased by several mbar in different gas compositions. No effect on cell load is observed in excess of ±1g.

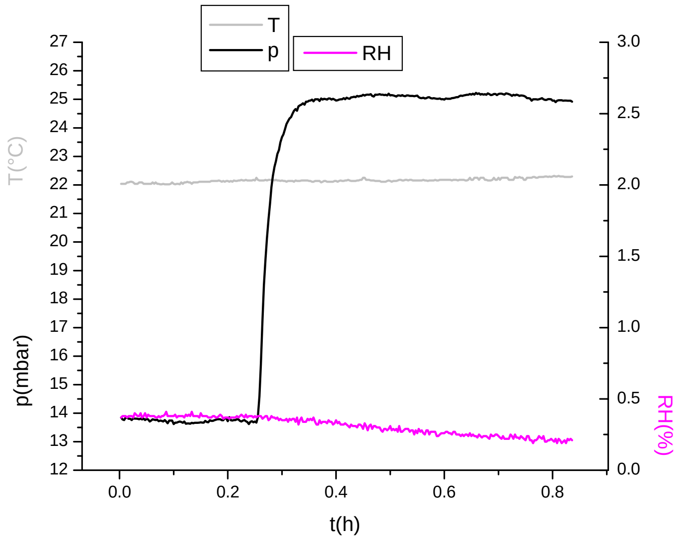

FIG. 4: T, p, RH trends when flow rate is changed from 40 l/h to 80 l/h for a gas mixture of 22.2% CO_2+ 77.7% Ar.

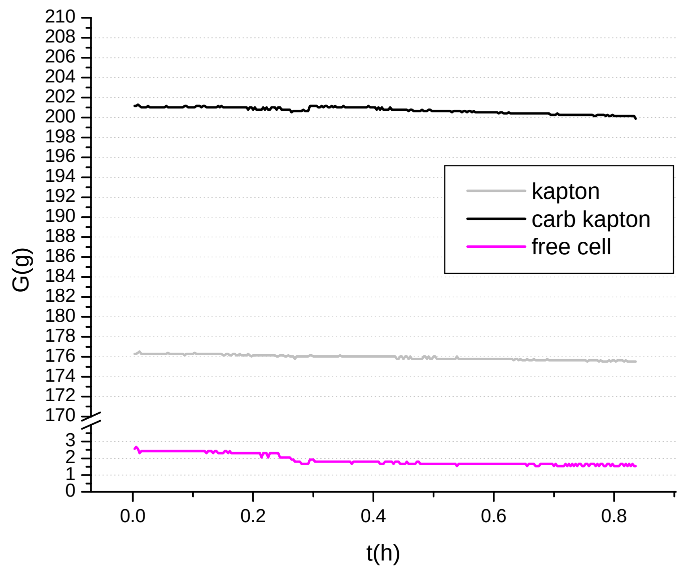

FIG. 5: Kapton, carbonated kapton and free cell trends when flow rate is changed from 40 l/h to 80 l/h for a gas mixture of 22.2%CO_2+ 77.7%Ar.

2.3 Humidity effect

Humidity effect is evaluated by a humidification and dehumidification test. To humidify box atmosphere, gas is bubbled in H_2O. When relative humidity arrives to 47-50%, the bubbler is by-passed and gas flows directly into the box so dehumidification starts. Fig 6 and 7 represent three humidity test in three different gas mixture: 22.2% CO_2, 100% Ar and 100% CO_2.

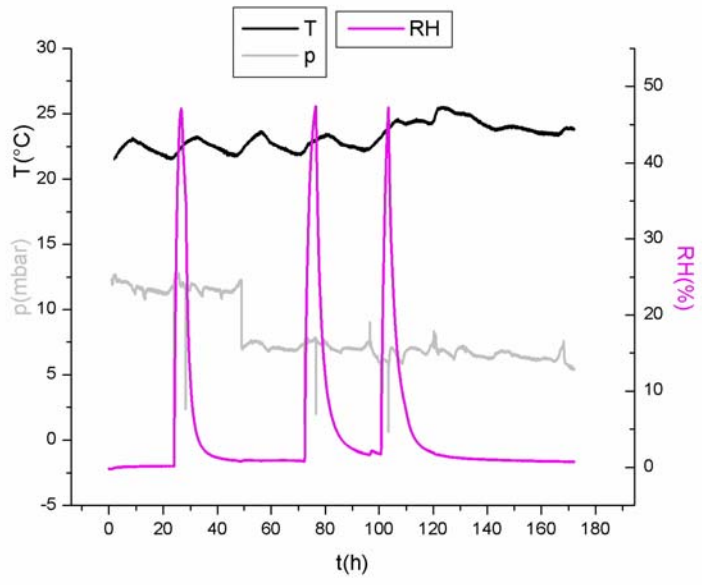

FIG. 6: T, p, RH trends for three humidity tests: the first peak is in 22.2% CO_2 (34.3 l/h), the second in 100% Ar (20 l/h), the last in 100% CO_2 (20 l/h). The down-peaks of pressure represent the connection and disconnection to the small water bottle.

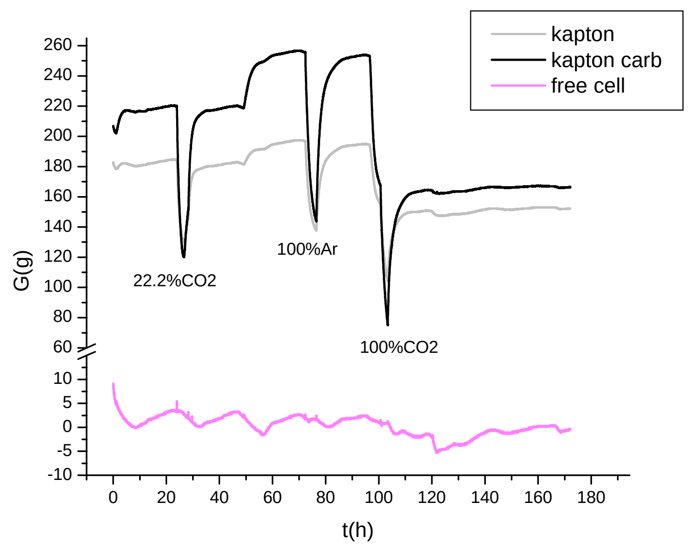

FIG. 7: Kapton, kapton carbonate and free cell trends during humidity test.

We tested the strips behavior in a limited range of RH, since typical variations the system is exposed to during flow composition changes or T fluctuation are well below 0.5%. Fig 8 and 9 show little RH variation in 100% Ar or 100% CO_2 for all six strips.

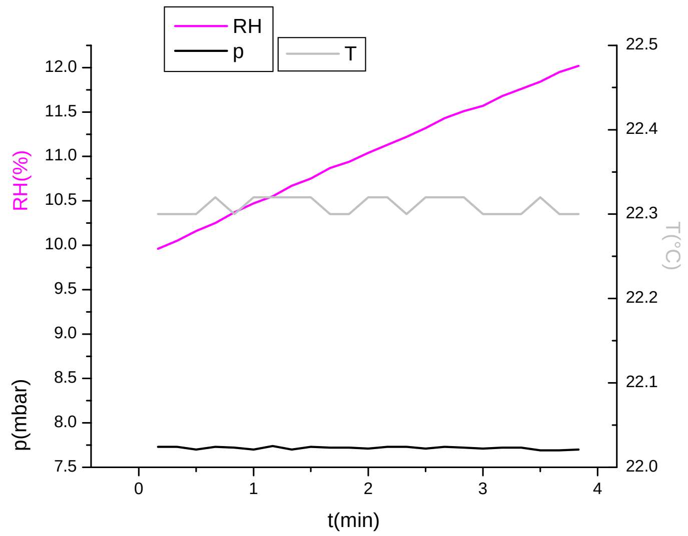

FIG. 8: T, p, RH variation in 100% Ar 20 l/h.

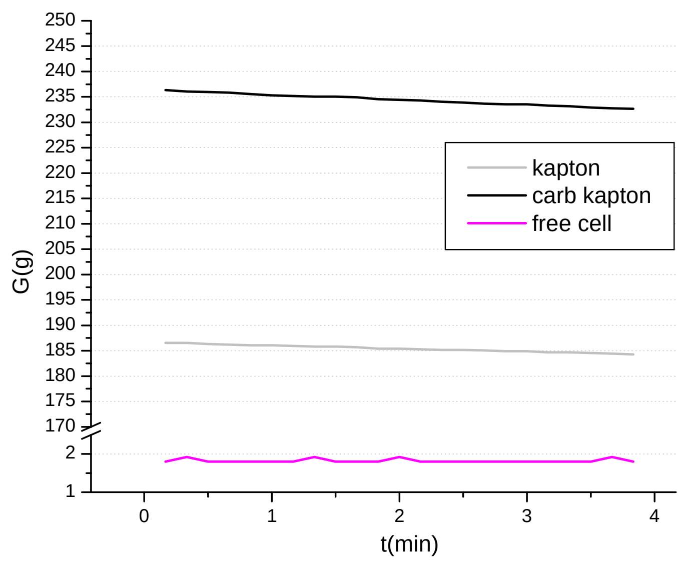

FIG. 9: Kapton, carbonated kapton and free cell trends during RH humidity change from 10% to 12% in 100% Ar (20 l/h).

A linear fit is introduced to find the influence of relative humidity on kapton and kapton carbonate; tab 3 summarizes the results as a slope coefficient β measured in g/(%RH) and β' measured in (%tension)/(%RH). Fig.10 shows an example of scatter-plot tension vs RH and its linear fit.

TAB 3: β and β' values.

Flow	**Strip**	**β g/(%RH)**	**β' (%tension)/(%RH)**
100%Ar	Kapton	-1.08±0.02	-0.58±0.01
	Kapton carbonate	-1.77±0.03	-0.75±0.01
100%CO_2	Kapton	-1.11±0.02	-0.77±0.01
	Kapton carbonate	-1.94±0.02	-1.31±0.02
100%CO_2	Mylar aluminised F	-1.29±0.05	-0.79±0.03
	Kapton carbonate-aluminised	-2.50±0.09	-3.21±0.12
100%Ar	Mylar	-1.20±0.02	-0.48±0.01
	Mylar aluminised E	-0.73±0.03	-0.33±0.01
100%CO_2	Mylar	-1.72±0.15	-0.82±0.07
	Mylar aluminised E	-0.99±0.07	-0.50±0.03

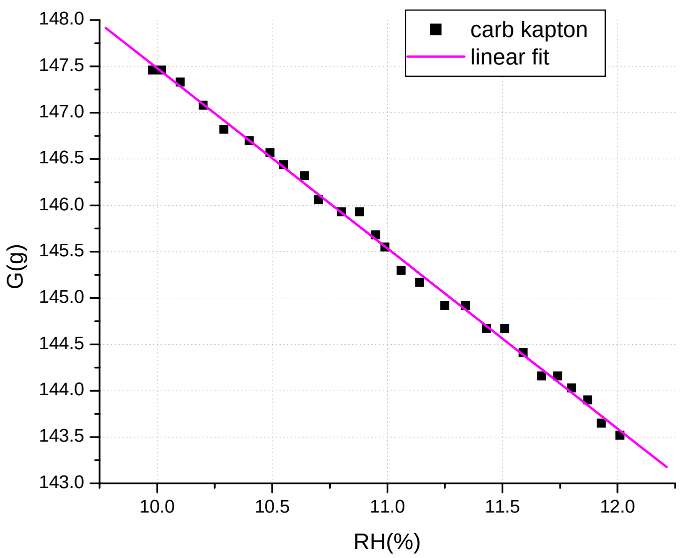

FIG. 10: Scatter plot example of tension vs RH for carbonated kapton in 100%CO_2 (20 l/h).

Typical tension/RH coefficient β and β' measured are of order 1g per point % of RH. During a typical gas concentration run RH changes by few tenths of %. Dependence of strip tension on RH is therefore well below ±1% under our experimental conditions.

2.4 CO_2 effect

CO_2 effect is evaluated at four different percentages in the gas mixture (with Ar): 0%, 22.2%, 50% and 100% CO_2; each mixture must be held for at least five hours, which are necessary to have the system stabilized. With increasing CO_2 percentage all the strips absorb gas particles, their volume (length) increases so tension on load cell decreases; this effect is recoverable when CO_2 percentage decreases. Setting 100%Ar as reference, it is possible to convert tension value to a percent decrease as shown in fig 11 and 12.

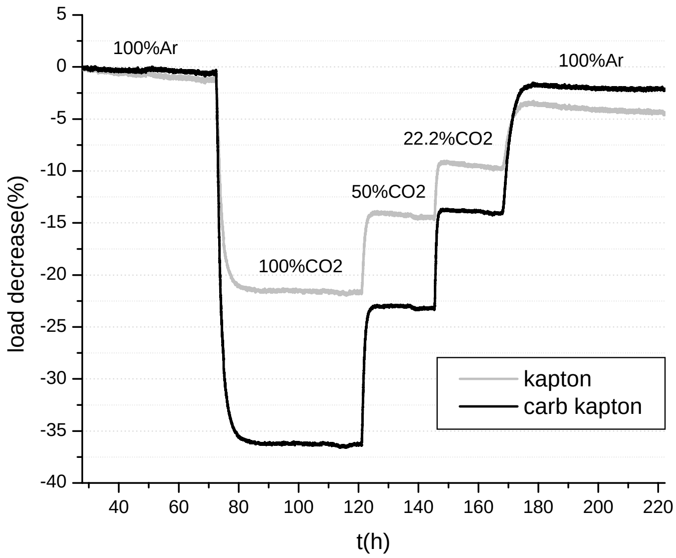

FIG. 11: Kapton and carbonated kapton load decrease (%) for four different CO_2 percentages of the gas mixture.

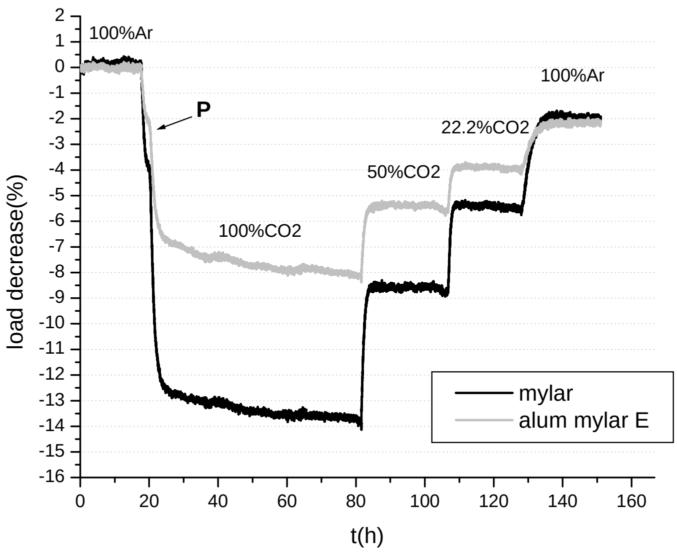

FIG. 12: Mylar and aluminised mylar E load decrease (%) for four different CO_2 percentages of the gas mixture. In P mixture is set at 22.2% CO_2, but after 2 hours Ar bottle finishes and mixture becomes 100% CO_2 before reaching stability.

In fig 12 kapton and carbonated kapton show a slow drift at 22.2% and 50% CO_2. In fig 38 also mylar and aluminised mylar E show a drift at 100% CO_2. We can explain it as a different adsorption speed of CO_2: at first adsorption is very quick, then, for last CO_2 particles, slows down. The slow drift observed is suggestive of an asymptotic behavior eventually reached after several days.

Moreover, in both figures, tension does not return to the starting value for 100%Ar: kapton and carbonated kapton fail to recover for 4% and 2% of load, which correspond to 8g and 4g (on an initial load of 200g); mylar and aluminised mylar E cannot recover about 2% of load which correspond to about 4g). This effect is probably due to usual polymers relaxation in time

Final result of our study is exposed in fig 13, where strips load decrease (%) to each CO_2 mixture is summarized in each point with an error of ±0.25%. In our load range (200±50g), used cells can appreciate tension variation of about 4g for a displacement of 1µm. In fig 14 we have converted % of load (g) in % of elongation (µm) considering strips length L_0=30cm and initial load G_0=200g.

Results show that mylar and kapton strips do change their volumetric and/or tensile properties in CO_2 atmosphere. This effect is well known for plastic materials and it is also employed in molecular sieve for CO_2 removal membrane (ref 19).

Mylar tensile behavior is always better than kapton one: for example at 50% CO_2 all types of mylar have an elongation less or equal to 1.5×10^{-3}%, instead carbonated aluminised kapton arrives to 5.2×10^{-3}%. Moreover carbonated aluminised kapton suffers more than all the other strips: it arrives to an elongation about 8.2×10^{-3}% in 100% CO_2. Glue presence actually worsens aluminised mylar response, especially at high percentage of CO_2, for example at 100% CO_2 relaxation doubles from 1.3×10^{-3}% without glue to 2.6×10^{-3}% with glue.

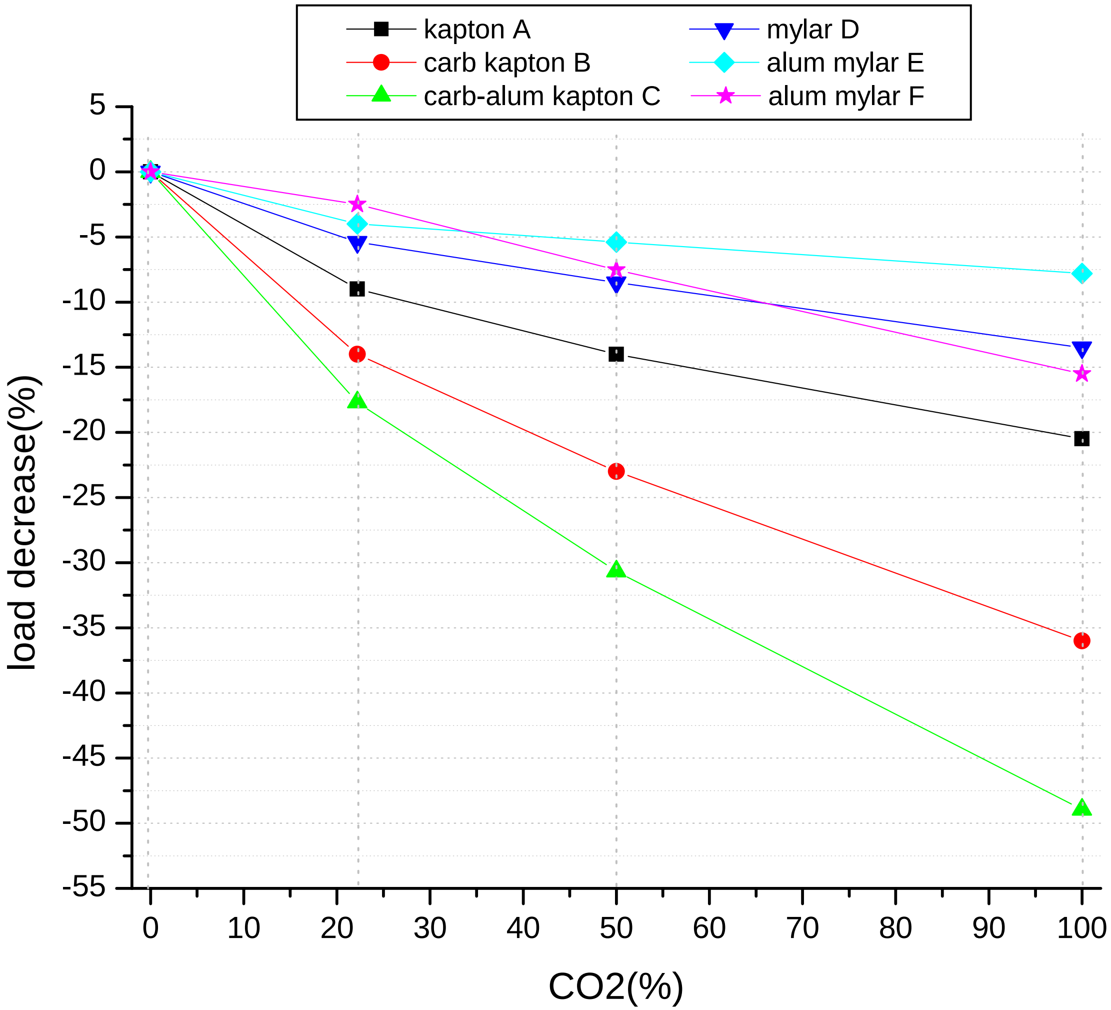

FIG. 13: Strips load decrease (%) at four different gas mixtures of CO_2 and Ar: 100%Ar, 22.2%CO_2, 50%CO_2 and 100%CO_2.

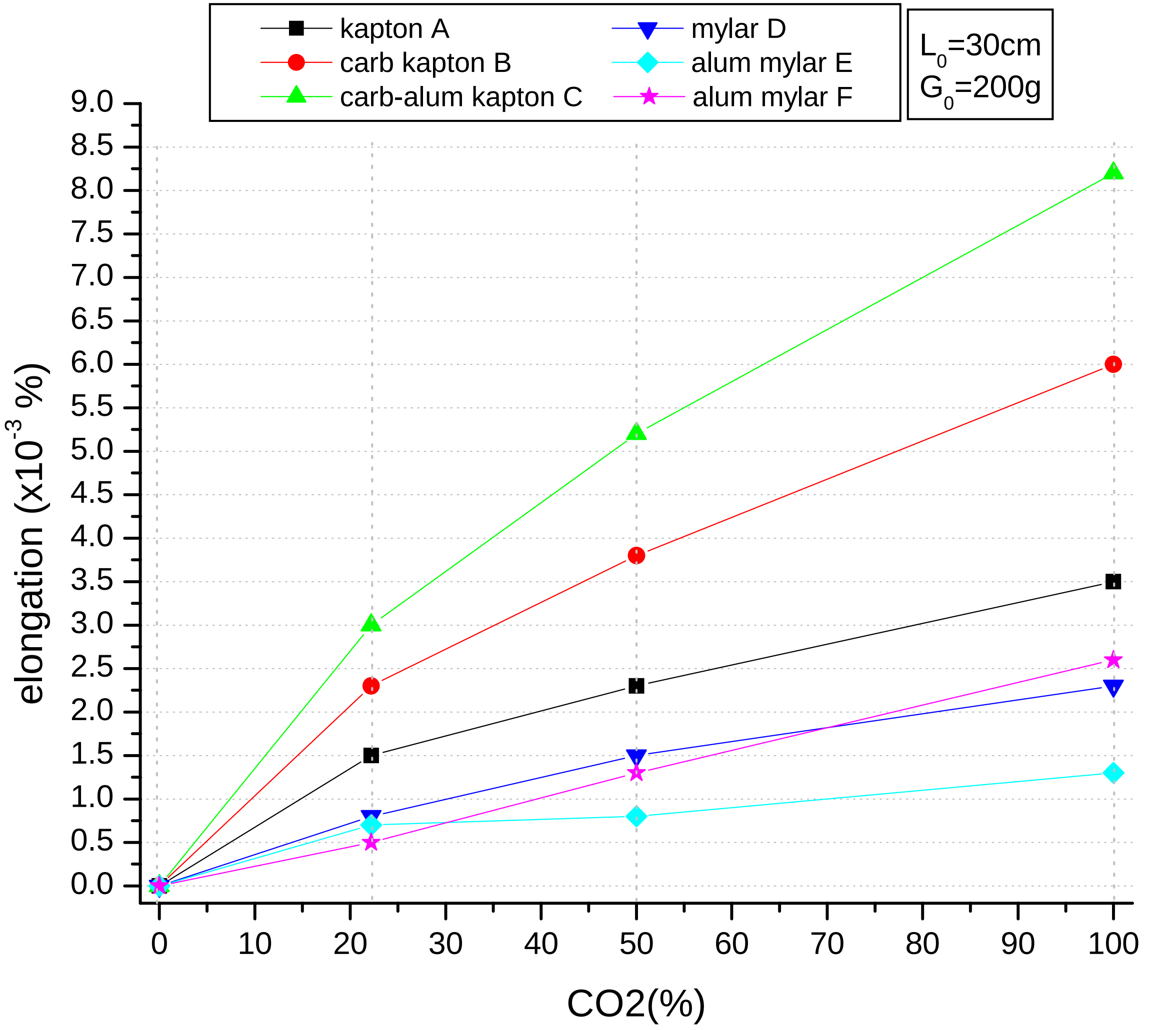

FIG. 14: Strips elongation (%) at four different gas mixtures of CO_2 and Ar: 100%Ar, 22.2%CO_2, 50%CO_2 and 100%CO_2.

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[2] "Straw Aging Studies with Ar/CO_2" (K. Lau, 11 June 2003 BTeV-doc-1891-v1).
[3] Cell 1: DS-Europe strain-gauge mod. 514QD, end scale 2kg, sn° 046113
[4] Cell 2: DS-Europe strain-gauge mod. 514QD, end scale 2kg, sn° 046117
[5] Cell 3: DS-Europe strain-gauge mod. 514QD, end scale 2kg, sn° 046112
[6] Temperature sensor PT100A
[7] RS Components Uncompensated pressure transducer, end scale 1.0psi
[8] Monolithic IC humidity sensor with integral thermistor, TO-5 can. Honeywell mod. IH-3602A
[9] Field point National Instruments mod. FP-AI-110 8-channel, 16-bit analog input modules
[10] Mass flowmeter ASA mod. F100/200 end scale CO_2 300 l/h, end scale Ar 400 l/h
[11] DUPONT, distributed by COVEME, kapton HN thickness 25±2µm, width 1cm, length ≈30cm, density 1.42 g/cm^2
[12] DUPONT, distributed by COVEME, carbonated kapton XC 50-65%C, thickness 25±2µm, width 1cm, length ≈30cm
[13] DUPONT, distributed by COVEME, carbonated aluminised kapton XC 50-65%C, thickness 25±2µm, cluster vapour deposition Al 150-200Å, width 1cm, length ≈30cm
[14] Mylar, thickness 12µm, width 1cm, length ≈30cm
[15] Aluminised mylar, thickness 12µm, vapour deposition Al 150-200Å, width 1cm, length ≈30cm
[16] Aluminised mylar, thickness 12µm, vapour deposition Al 150-200Å, width 1.2cm, length ≈30cm
[17] LAMINA mylar straw obtained by rolling a strip of aluminised mylar and sticking covering borders; external diameter 1.5cm, thickness 30 µm. Straw used for FINUDA experiment.
[18] L.Benussi et al., Nucl. Instrum. Meth. **A361** (1995) 180-191; L. Benussi et al., Nucl. Instrum. Meth. **A419** (1998) 648-653.
[19] "Recent Developments in CO_2 Removal Membrane Technology" (Dortmund, Doshi, 1999 UOP LLC, Des Plaines, Illinois)