Properties of the insulators:

Influence of the electrical charges

presented by Christelle GUERRET

Chargée de recherche du CNRS

to obtain the "Habilitation à Diriger des Recherches"
What role for the electrical charges?
I. Examples of industrial applications for the insulators: Evidencing of the role of the electrical charges.
   1. Modification of friction and adhesion
   2. Flow and trapping of the electrical charges.

II. Contribution of the electrostatic forces to the adhesion of the materials:

III. Characterization of the properties of charges flow and charges trapping:
      SEMM method and simulations

IV. Conclusions and Prospects
Electro-mechanical sensor of acceleration for air-bag

I. Examples of industrial applications for the insulators

I.1. Modification of friction and adhéssion

Principle:
- metallic ball in an insulator guide
- maintained by a magnetic field
- during a strong acceleration the ball overcome the magnetic field and establish electrical contact.

Inactivation of the sensor because of the adhesion of the ball on the insulating guide wall

Fundamental study of the interaction between a charged metallic ball and an insulating plane

Usefulness of the comprehension of the triboelectrification phenomenon

*Action Concertée Incitative
I. Examples of industrial applications for the insulators

I.1. Modification of friction and adhésion

Pieces for mitigation tap

*Action Concertée Incitative

Principle:
- simultaneous control of the flow and of the temperature of water
- superposition of the holes of both ceramic disks
- sliding one over the second during the use

unusable tap due to the adhesion of the two ceramic disks

Usefulness of the comprehension of the triboelectrification phenomenon between two similar materials
I. Examples of industrial applications for the insulators

I.2. Transport and trapping of the electrical charges

yarn-guide for textile industries

Performances:
- strength to abrasion
- strength to chemical corrosion
- high mechanical characteristics
- used materials: $A_2O_3$, $A_2O_3+Zr$, $TiO_2$

Yarn adhere to the yarn-guide during the use when the friction coefficient is too high

Previous study*:
link between the friction coefficient and the ability of the material to trap charges

Importance of the ability of the material to trap charges: study of $TiO_2$

I. Examples of industrial applications for the insulators

I.2. Transport and trapping of the electrical charges

Problem of "mixing" of the colors due to the electrostatic fields created by the charging of the spacers

Definition of "trapping insulators" and "conductive insulators"

Characterization of the behavior of dielectrics under electronic irradiation: transport and trapping of charges...

I. Examples of industrial applications for the insulators

I.2. Transport and trapping of the electrical charges

**Sparking plugs**

**Conditions of use:**
- corrosive medium
- strong variations of temperature and pressure
- high voltage
- miniaturization

**Aging of the materials**

**Strength to dielectric breakdown in different ranges of temperature**

**Dielectric breakdown of the sparking plugs**

**Transport and trapping of charges...**

Links with the dielectric rigidity of insulators

Behavior under aging and temperature variations ...

Applications:
- motorbike
- automobiles
- boats
- rockets...

* PhD thesis of Ecole des Mines de St Etienne, Direction D. Goeuriot
II. Contribution of the electrostatic forces to the adhesion of the materials:
   1. Example of the charged metallic ball on an insulating plane
   2. Triboelectrification between two similar materials
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Experiences

Objectives of the study:
- evidencing of the strength of electrostatic forces
- "soft" injection of the electrical charges in an insulator?

\[
\sin \alpha - k \cos \alpha = \frac{k}{mg} F
\]
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Experiences

- Surface potential $V_s$ vs. Total charge $Q_{\text{total}}$ (pC)
- Area 1: no breakdown
- Area 2: random breakdown
- Area 3: systematic breakdown

- Injected charge: $Q_{\text{totale}}$

- Limit angle $\alpha$ (degrees) vs. Total charge (pC)
  - Area 1
  - Area 2
  - Area 3
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Simulations (Flux 2D)

Numerical Model*:
- axial symmetry, charge in the ball \( Q_i \), potential \( V_s \)
- ball on an insulating disk \((\varepsilon_r)\) thickness \( h \) \((R=20\text{mm})\)
- insulator on a grounded metallic plane plan

\[ Q_i = C \cdot V_s \]

* collaboration with N Burais, CEGELY, EC Lyon

Influence of the sample holder

Dominant role of \( \varepsilon_r \)
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Analytical approach

Hypothesis of the calculation:
- conducting ball held on a semi-infinite dielectric
- case (a): charged sphere $Q_i$, non charged plane
- case (b): charged sphere $Q_i$, charged plane $Q_t$
- $Q_t$ ponctual charge

Case (a) non charged plane: 2 infinite series of image charges

\[ q_{i+1} = A^i q_i \frac{1}{i+1} \]

A = $(\varepsilon_r - 1)/(\varepsilon_r + 1)$
due to the interface vacuum/dielectric

\[ q_i = -A^i q_i \frac{1}{i} \]

$\Delta_i$ = distance $q_i$ - center O
$q'^i$ symmetric of $q_i$ / interface

\[ \Delta = \frac{i}{i+1} R \]

\[ V_s = \sum_{i=1}^{\infty} \frac{q_i}{4\pi \varepsilon_0 (R - \Delta_i)} = \frac{1}{4\pi \varepsilon_0 R \ln(1-A)} A Q_i \]

\[ F = \frac{1}{4\pi \varepsilon_0} \sum_i \sum_j \frac{q_i q_j}{(2R - \Delta_i - \Delta_j)^2} = \frac{1}{4\pi \varepsilon_0 R^2 (\ln(1-A))^2 Q_i^2} \]

\[ K_e = \sum_i \sum_j A^{i+j-1} \frac{ij}{(i+j)^2} \]

sapphire ($\varepsilon_r = 10$) $K_e = 4.69$, quartz ($\varepsilon_r = 4.3$) $K_e = 0.91$
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Analytical approach

Case (b) charged plane $Q_t$: 4 infinite series of image charges

$$V_s = \sum_{i=1}^{\infty} \frac{q_i}{4\pi\varepsilon_0(R-\Delta_i)} + \sum_{i=1}^{\infty} \frac{q_i^d}{4\pi\varepsilon_0(R-\Delta_i^d)} = \frac{1}{4\pi\varepsilon_0 R} \left[ -\frac{A}{\ln(1-A)} Q_i + \frac{2}{\varepsilon_r+1} Q_t \right]$$

$$F = \frac{1}{4\pi\varepsilon_0 R^2} \left[ \left( \frac{A}{\ln(1-A)} \right)^2 Q_i^2 K_e - \frac{2}{\varepsilon_r+1} Q_i Q_t \right]$$
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

**Analytical approach**

**Area 1**: \( Q_i = Q_{\text{totale}} \)

**Area 2**: Random breakdown

**Area 3**: \( Q_i = Q_{\text{total}} - Q_{\text{released}} - Q_t \)

Systematic breakdown

\( Q_{\text{released}} = 6000 \, \text{pC}, \quad Q_{\text{injected}} = 200 \, \text{pC} \)

\[
V_s = \frac{1}{4\pi\varepsilon_0 R^2} \frac{A}{\ln(1 - A)} Q_i
\]

\[
F = \frac{1}{4\pi\varepsilon_0 R^2} \left( \frac{A}{\ln(1 - A)} \right)^2 \cdot Q_i^2 \cdot K\varepsilon
\]
II. Contribution of the electrostatic forces to the properties of materials

II.1. Charged metallic ball on an insulating plane

Summ up*

Applicative results: Adhesion of the ball is an electrostatic phenomenon

\[ F_{\text{electrost}} = \frac{1}{4\pi\varepsilon_0 R^2} \left( \frac{A}{\ln(1-A)} \right)^2 Q^2 K_{\varepsilon} = \frac{\text{Cte}}{4\pi\varepsilon_0 R^2} \frac{Q_i^2}{\varepsilon} \]

sapphire (\(\varepsilon_r=10\)), Cte = 1.08
quartz (\(\varepsilon_r=4.3\)) Cte = 0.36

Choice of the dielectric: nature, thickness
Dimensions of the ball

Fundamental results:
Mechanism of the ball-plane interaction under electronic injection: 3 steps

1- Small quantities of charges injected in the ball: all the charges stay in the sphere
2- Breakdown of the surrounding medium, Release of the charges present in the ball.
3- Systematic breakdown coupled with partial injection in the insulating plane and followed by a recovery of the injection in the ball

Remarks:
- stable volume trapping
- unusable for a "soft" injection

II. Contribution of the electrostatic forces to the adhesion of the materials:

1. Example of the charged metallic ball on an insulating plane
2. Triboelectrification between two similar materials
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Position of the problem *

- **Triboelectrification between 2 different materials:** well-known mechanism in the case of two metals, no clear mechanism as soon as one of the material is an insulator

- **Triboelectrification between 2 similar materials:** not understood, not evidenced at the microscopic scale

- **Numerous studies, due to recent development of the apparatus** (SFA, AFM, EFM)

II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Results of the literature

Surface Force Apparatus: Mica/Silica, in dried N₂

➢ attraction at long distance (>3 µm)
➢ density of the electrical charges: 10 mC/m²

AFM: Tungsten/ TiO₂ stoech. or non/stoech, Ultravacuum.

➢ <15nm: van der Waals forces are dominant
➢ >15nm: Electrostatic forces for TiO₂ stoech
➢ density of the electrical charges : 10⁻³ mC/m²

AFM: Stability of charges in thin layer of Al₂O₃.

➢ deposit of charges on the oxyde surfaces, by application of a potential or by friction
➢ density of the electrical charges : 10⁻⁵ mC/m²
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Adhesion between two similar insulating surfaces*

OBJECTIVE:
- Evidencing of the triboelectrification between two similar materials
- Characterization of the contribution of the resulting electrostatic force on the adhesion

EXPERIENCE:
- Surface Force Apparatus of Ecole Centrale de Lyon (SFA)
- 2 antagonists in monocrystalline alumina (sapphire)

Sphere-plane contact (R=3mm)

sphere A: very smooth area of contact (R_m=qq nm)

sphere B: presence of asperities in the contact area

* Action Concertée Incitative, "Tribosurfélec", collaboration IFoS- LTDS
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Case of the smooth sphere A

- Before friction:
  - attraction due to van der Waals forces \( \frac{F_z}{R} = -\frac{A}{6D^2} \)
  - apparition of a viscous damping due to the formation of a water meniscus vacuum non suffisant to remove the remaining water

- After friction:
  - apparition of a long distance force, electrostatic charges

![Graphs and SEM Observation]

- **Before friction**: Normal Force \( F_z (\mu N) \)
- **After friction**: Visco-courant damping \( \omega (N/m) \)

**SEM Observation**

- Diameter of the white spot 2mm
- Negatives charges

**Equation**: Log (D) vs. Log (Fz) slope 2

**Legend**:
- van der Waals attraction
- attraction due to meniscus
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Case of the sphere B : attraction after friction

Stop of the unloading, at imposed distance:
attraction decreases with time

\[ F_z = F_0 \exp\left(-\frac{(t - t_0)}{\tau}\right) \]
\[ \tau = 256 \text{ s} \]

Specific way to measure the force during a small time of unloading (some s):
attraction decreases with distance
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Attraction after friction: Model of Burnham & al

Model of Burnham, Colton et Pollock (BCP)

1st term:
- due to the vacuum/dielectric interface
- always attractive

2nd term:
- depends on the signs of \( Q_t \) and \( Q_p \)
- even if \( Q_t \) and \( Q_p \) have the same sign, at low distance the first term dominates

In our case:

\[
4\pi\varepsilon_0 F = -\frac{Q_t^2}{4(D+A)^2} \left( \frac{\varepsilon - 1}{\varepsilon + 1} \right) + \frac{RQ_t Q_p}{z(2D+A+R)^2} \left( \frac{\varepsilon - 1}{\varepsilon + 1} \right)^2
\]

\( \varepsilon = 10 \) for \( \text{Al}_2\text{O}_3 \)
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Attraction after friction: Model of Burnham & al

- **Sapphire-sapphire friction**
- **Best fit between 0 and 100 nm:**
  - Charges of the same sign
- **Parameters of the fit:**
  - $Q_t = 4.76 \times 10^{-15}$ C, $\Rightarrow \sigma_t = 9.2 \times 10^{-2}$ mC/m$^2$
  - $A = 26$ nm
  - $Q_p/Z = 2.2 \times 10^{-7}$ C/m

For comparison:

- **Burnham et al: diamond/graphite**
  - $Q_t = 2 \times 10^{-16}$ C, $\Rightarrow \sigma_t = 4 \times 10^{-5}$ e/Å$^2$
  - $A = 10$ nm,
  - $Q_p/Z = 4 \times 10^{-8}$ C/m, $\Rightarrow \sigma_p = 8 \times 10^{-7}$ e/Å$^2$

- **Sounilhac et al: tungstene/TiO$_2$**
  - $Q_t = 0.54 \times 10^{-15}$ C
  - $A = 68$ nm
  - Charges of the same sign
II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Modification of the adhesion due to triboelectrification*

Sum up

(1) Instantaneous measurement, Force at low distance (0-100nm) :

- Adhesion is modified by the presence of an electrostatic force,
- Quantification of the charges (BCP model)
- Charges are mobiles on the surface: t = 256s,
- Comparable time with diffusion's times found in the literature on wet alumina surfaces or on polluted one's $\tau \approx 200s$.

II. Contribution of the electrostatic forces to the properties of materials

II.2. Triboelectrification between two similar materials

Modification of the adhesion due to triboelectrification*

(2) Long time, Force at long distance (1-5µm):

- attraction at long distance in the friction area
- observed on the two types of sphere (smooth or with asperities)
- measurable several days after the friction test
- charge observed with a SEM

![Graph showing relationship between Normal Force, Viscous damping, and Distance sphere-plan D (nm)]

I. Examples of industrial applications for the insulators: Evidencing of the role of the electrical charges.

1. Modification of friction and adhesion
2. Flow and trapping of the electrical charges.

II. Contribution of the electrostatic forces to the adhesion of the materials:

1. Example of the charged metallic ball on an insulating plane
2. Triboelectrification between two similar materials

III. Characterization of the properties of charges flow and of charges trapping: SEMM method and simulations

1. "Miror" method and influence current
2. Simulation of the injection of electrons

IV. Conclusions and Prospects
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Mirror method (SEMM)

2 Steps:
- injection of high energy electrons (10-30 keV)
- lecture by a low energy beam (300-1 keV)

trapping of charges in the insulator
device of the electron of the lecture beam
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Mirror method (SEMM)

Approximation of a punctual charge

\[ \frac{1}{d} = \left( \frac{4 \cdot L}{d'} \cdot \frac{1}{A_{\infty} Q_p} \right) \cdot V_i \]

Evaluation of the quantity of trapped charges

\[ A_{\infty} = \frac{1}{2\pi\varepsilon_0 (\varepsilon_r + 1)} \]

Multipolar development (isotropic material)*

\[ \frac{1}{d} = K \{ \frac{V}{A Q_p} - 2\beta R_0^2 \left( \frac{V}{A Q_p} \right)^3 \} \]

Form of the charges distribution:

\[ \beta > 0 : \text{charges on the surface} \]
\[ \beta < 0 : \text{charges in the depth} \]

III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Method of the influence current (ICM)

\[ Q_M(t) = \frac{1}{K_e} \int_0^t I_M(t) \cdot dt \]

charges injected in the material \( \rightarrow \) influence charges on the sample holder

\[ I_M = (1 - \sigma_{EES}) \cdot I_0 + I_S + I_V + I_{TE} \]
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of polycrystalline alumina samples*

- alumina powder + various sintering aids
- sintering in liquid phase
- example of 2 materials A and B
- ajouts de frittage différents joints de grains différents

<table>
<thead>
<tr>
<th>Material</th>
<th>Vitreous Phase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A : Industrial</td>
<td>15.9</td>
</tr>
<tr>
<td>B : Laboratory</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Characterization of the dielectric stiffness:

$E_B > E_A$  $E_A > E_B$

III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of polycrystalline alumina samples

<table>
<thead>
<tr>
<th>Matériau Industriel (A)</th>
<th>0°C</th>
<th>40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_P$ (pC)</td>
<td>94</td>
<td>0</td>
</tr>
<tr>
<td>$Q_M$ (pC)</td>
<td>98</td>
<td>108</td>
</tr>
<tr>
<td>$R = \frac{Q_P}{Q_M}$</td>
<td>96 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Matériau Laboratoire (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_P$ (pC)</td>
</tr>
<tr>
<td>$Q_M$ (pC)</td>
</tr>
<tr>
<td>$R (%) = \frac{Q_P}{Q_M}$</td>
</tr>
</tbody>
</table>

Trapped charge (SEMM)

Stabilization Ratio

Injected Charge (ICM)

Flow of charges

Trapping of charges

<table>
<thead>
<tr>
<th>Composition A</th>
<th>$J_0 = 15 \times 10^{-5}$ A/cm²</th>
</tr>
</thead>
</table>

| Composition B | $J_0 = 15 \times 10^5$ A/cm² |

0°C vs. 40°C
Effects of the microstructure on the flow and on the trapping of the charges: favorable cases to optimize the dielectric stiffness

At low temperature:
- crystallized secondary phase (material B): deep traps
  "Trapping" insulator

At high temperature:
- vitrous secondary phase (material A): traps of weak deepness, favorable to the flow of charges
- weak number of grain joints
  "Conductive" Insulator
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of a SC with high forbidden gap: TiO₂ rutile*

Characteristics of TiO₂ rutile:
- SC with high forbidden gap: 3.1 eV
- Resistivity $R > 10^{13} \, \Omega \text{cm}$ (sensibility to oxygen)
- Anisotropy of the permittivity: $\varepsilon_r = 86$ at $T_{room}$ in the X,Y plane
  - $\varepsilon_r = 170$ at $T_{room}$ along Z = [001]

Structure of TiO₂ rutile

* Temga Temga, Mémoire de Thèse, Lyon, 2004
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of a SC with high forbidden gap: TiO$_2$ rutile*

Injection along the axe X= [110]

Anisotropy of the obtained mirror

Trapping of the electrons near the Ti ions

Deep trapping:

\[
\frac{1}{d} = K \left\{ \frac{V}{AQ_p} - 2\beta R_0^2 \left( \frac{V}{AQ_p} \right)^3 \right\}
\]

Cylindrical Distribution radius \( R = 2\,\mu m \) and deepness \( h = 280\,\mu m \)

III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of a SC with high forbidden gap: TiO$_2$ rutile*

Injection along axe Z= [001]

Circular mirror, analytical model taking into account the anisotropy of $\varepsilon_{r}^*$

Transversal Isotropic Material: punctual charge

$$\frac{1}{d} = \left( \frac{4 \cdot L \cdot 2\pi \varepsilon_0 (\varepsilon_r + 1)}{Q_p} \right) \cdot V_i$$

Transversal Isotropic Material: homoïdal distribution

$$\frac{2c}{d} = \frac{4H}{\phi} \left\{ \frac{\sin}{\sh} \right\} \left( \frac{2c \cdot 8\pi \varepsilon_0 E_{cin}}{Q} \right)$$

* developed by G DAMAMME, PHDthesis T TEMGA, publication in preparation
III. Characterization of the properties of transport and trapping of the charges

III.1. Mirror method and influence current

Characterization of a SC with high forbidden gap: TiO₂ rutile*

Importance of leakage current

Modification of the ICM method*

\[ I_M = (1 - \sigma_{EES}) \cdot I_0 + I_S + I_V + I_{TE} \]

** proposition HJ Fitting,


** proposition HJ Fitting,
I. Examples of industrial applications for the insulators: Evidencing of the role of the electrical charges.

1. Modification of friction and adhesion
2. Flow and trapping of the electrical charges.

II. Contribution of the electrostatic forces to the adhesion of the materials: 

1. Example of the charged metallic ball on an insulating plane
2. Triboelectrification between two similar materials

III. Characterization of the properties of charges flow and of charges trapping: SEMM method and simulations

1. "Miror" method and influence current
2. Simulation of the injection of electrons

IV. Conclusions and Prospects
III. Characterization of the properties of transport and trapping of the charges

III.2. Simulation of the injection of electrons*

** Self-consistent model **

Injection of high energetic electrons in an insulator**: - backscattered electrons \( \eta \) - penetration in the bulk PE - generation of e-h pairs (secondary e) - secondary emission - e-h recombination - trapping, effect of the electric field

Principle of the simulation:
- model with 1 dimension
- determination for each time and for each position \( x \) in the sample of the quantity of charges

Principle:

\[
\begin{align*}
J(x,E) & = J_0 (1 - \eta) \exp \left[ -4.605 \left( \frac{x}{R(E,z)} \right)^p(z) \right] \\
\frac{g_i}{\tilde{A}} & = 0.146 \cdot \left( \frac{E_0}{\text{keV}} \right)^{-0.3} \exp \left[ -7.5 \left( \frac{x}{R} - 0.3 \right)^2 \right] \\
j^R_T(x) & = \left[ j^R_T(x \pm \Delta x) + \frac{1}{2} j_0 g_1(x) \Delta x \right] \cdot W(x) \\
j(x) & = -j_{PE}(x) - j_{ET}(x) + j_{ER}(x) + j_{HT}(x) - j_{HR}(x)
\end{align*}
\]

* Collaboration with Pr HJ Fitting, University of Rostock, Ph.D Thesis X Meyza, C Dutriez, and M Touzin

III. Characterization of the properties of transport and trapping of the charges

III.2. Simulation of the injection of electrons*

Self-consistent model

Very short injection:
- determination of the instantaneous secondary emission curve (negligible $V_s$)
- validation of the model

Self-regulated Phenomenon:
- negatives charges are injected in the depth of the sample leading to the creation of a high negative potential and increase de secondary emission
- incoming charges are slow down
- less and less charges are injected, surface potential and secondary emission become stable
III. Characterization of the properties of transport and trapping of the charges

III.2. Simulation of the injection of electrons*

Development of a new model*:
- to take into account the effect of the temperature through the Poole-Frenkel effect
- to take into account the anisotropy of the diffusion and drift due to the field

Example of simulation:
effect of the electronic traps number on the decrease of the influence current

* Collaboration with Pr HJ Fitting, University of Rostock, PHDThesis C Dutriez, and M Touzin
I. Examples of industrial applications for the insulators: Evidencing of the role of the electrical charges.

1. Modification of friction and adhesion
2. Flow and trapping of the electrical charges.

II. Contribution of the electrostatic forces to the adhesion of the materials:

1. Example of the charged metallic ball on an insulating plane
2. Triboelectrification between two similar materials

III. Characterization of the properties of charges flow and of charges trapping: SEM M method and simulations

1. "Miror" method and influence current
2. Simulation of the injection of electrons

IV. Conclusions and Prospects
Importance of the triboelectrification

Evidencing of the importance of the electrical charges for the properties of friction and adhesion

Improvement of the dielectric strength by determination of the structural parameters leading to a better accommodation of the injected charges depending on the temperature of use: "trapping" insulators or "conductive" insulators

Electromechanical sensor of acceleration for airbag

Understanding of the mechanisms of injection and trapping of the electrical charges:
- experiments
- simulation

Pieces for mitigation tap

yarn-guide

FEG screen

Sparking plug
IV.2. Prospects: The polymers insulators

- Study of the trapping and flow of electrical charges in the polymers*

- Link between triboelectrification of the melt and emergence of defects during the extrusion of molten polymers**

- Utilization of ICM and SEMM methods to characterize the nanostructured materials

- Study of polymers/ conductive charges composites: CNT-Elastomers, PANI-BuA...***


** Thèse F. Flores, S. Tonon, A. Lavernhe-Gerbier, F. Flores, A. Allal, C. Guerret-Piécourt J. of Non-Newtonian Fluid Mechanics, (accepté, sous presse)

*** 1 brevet déposé, V. Datsyuk, C. Guerret-Piécourt, S. Dagréou, L. Billon, J.-C. Dupin, E. Flahaut, A. Peigney, C. Laurent Carbon (sous presse)
THANKS

Sandrine BEC, Gilles DAMAMME, Vitaliy DATSYUK, Cédric DUTRIEZ, Hans-Joachim FITTING, Fabrice FLORES, Dominique GOEURIOT, Denyse JUVÉ, Xavier MEYZA, Olivier GUERRET, Fabrice SEGAULT, Temga TEMGA, André TONCK, Sébastien TONON, Matthieu TOUZIN, Daniel TRÉHEUX .../...

- Laboratoire des Solides Irradiés (SESI) à l'Ecole Polytechnique
- Laboratoire d'Analyse et d'Architecture des Systèmes à Toulouse
- Laboratoire de Tribologie et de Dynamique des Systèmes de l'ECLyon
- Laboratoire d'Ingénierie et Fonctionnalisation des Surfaces de l'ECLyon
- Laboratoire de Physico-Chimie des Polymères de Pau