ACTION OF THE SAND IN ULTRA-FAST FUSES. PROBLEMATIC

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Abstract: *FERRAZ-SHAWMUT intends to improve his knowledge about design and manufacturing of fuses. One very crucial point is the relationship between sand and the behaviour of the electrical arc during fuse-operation. In the past many tests have been carried out, in which the parameters of the manufacturing-process were adjusted or modified, and afterwards arcing parameters were measured. It was very difficult to draw out evidence of correlation.*
One idea is to characterize not only the manufacturing-process but its results. How are the sand grains arranged, specially around the fuse-element and even more specially around the necks where the arc is initiated. The knowledge of the arrangement of sand-grains will be necessary for any understanding and physical modelling of electrical arc as phenomenon involving materials.
FERRAZ-SHAWMUT, Ecole des Mines de Saint-Etienne and LTPCM-Grenoble are collaborating in that way.

Keywords: *(e.g. electric fuse, ignition arc, current limitation, over voltage)*

1. Introduction

Since at least 1666 and the fundamental discovery of inertia by Isaac Newton, scientists know that it is not possible to pass from a physical state nr 1 to a state nr 2 within a null time. Concerning fuses, it means that when occurs the blowing, the current will decrease within a few time. In other words, fuse becomes a variable resistance, which value increases from a very low value to infinity. The physical principle of this variable resistance is nothing more than an electrical arc.

Another way for watching to the operation of the fuse is to consider that electrical energy $\frac{1}{2}Li^2$ inside the circuit must be absorbed. Then the arc is nothing more than a machine transforming rapidly electrical energy to thermal energy. The materials around arc are heated and play as a storage-tank. After the electrical current reaches zero, the heat can be dispatched into the surroundings.

Sand is in charge to absorb a large quantity of this energy, thanks to its high melting temperature and melting energy.

Sand is also in charge, thanks to its porosity to control the flow of highly energized materials (hot liquid, gazes and plasmas) and hence to control the arc-voltage.

2. Problematic

Further to these qualitative considerations, the job of the engineer is to give values to the physics.

In that way, many studies have been carried out from theoretical and experimental points of view [1 to 10]. There is today an evident tendency to propose as ROCHETTE [9-10] and CLAIN [10], a model of the electrical arc where the sand is a porous material through which runs a gaseous flow in addition with a thermal flux. The porous material is considered as homogeneous. In fact, this is not true and we can suspect that electrical arc will be deterred by the location and the size of the first grain it will meet. Vivier [11] did the demonstration that even when all the fuse-manufacturing parameters are controlled and repeated, a variability of the arc-voltage as soon as within arc-ignition, could be observed. His observations were specially significant because he used simple fuses, with only one row of necks in a large sand core. Indeed, in case of many rows in series and in parallel, the variability is erased because of statistical effects.

The problem is to explain how could the grains-arrangement deter the arc-ignition. Hence, it appears that it is necessary to describe the grains-arrangement.

3. Characterizations of the sands:

Particular materials are very common on the surface of the earth and used in many industrial and human activities. Without any order, we can quote as examples : sands (of course), seeds (corn, rice, beans, nuts), medical powders, washing powders, wood-sawdust, concretes, etc… Nevertheless, scientists have not yet found the models in order to describe their behaviour and even more, they have not yet a good understanding of their behaviour.

When we try to characterize powders or sands, a triple question is asked :

- do you want to characterize the grains (their shape, their size, their material…) ?
- do you want to characterize the sand as a continuous material (quasi-solid when it is motionless and quasi-liquid when it is moving)?
- do you want to characterize the arrangement of the grains within a quasi-solid state ?

3.1. Characterization of the grains :

Sand grains can be characterized by their material(s), including the purity of this material and eventually the presence of two or several materials.

They can be also characterized by the size, or better by the size-distribution of the grains.

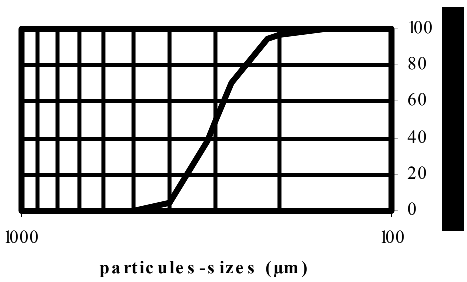

Fig.1 : usual cumulative distribution-curve for sand

The document API - Recommended Practice 58 gives a chart allowing to class grains versus two parameters so called sphericity and rondicity :

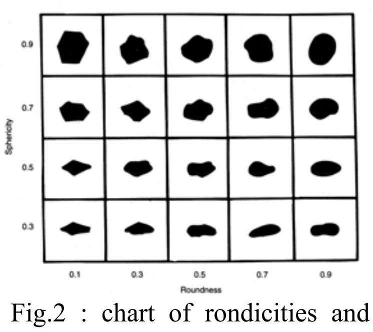

Fig.2 : chart of rondicities and sphericities according to API 58.

3.2. Characterization of sand as continuous material :

Two series of parameters could be used in order to characterize sands as continuous materials. Some of these parameters consider sands as quasi-solids :

- permeability (measurement of the velocity of a gaseous or liquid flow through a porous material),
- measurement of the shear-stress (Jenike-cell).

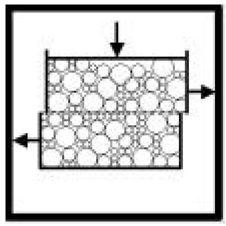

Fig.3 : Principle of Jenike-cell : a two-parts-box is filled with powder. Then it is submitted to shearing-strains.

Other parameters consider sands as quasi-liquid :

- flow-rate and angle of repose.

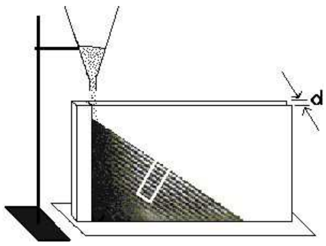

Fig.4 : measurement of flow-rate and angle of repose.

3.3. Characterization of the arrangement of the grains within a quasi-solid state :

New developments in picture-analysis allow to better characterize the arrangements of granular materials. We can quote the works carried out by SERRA [11-12] and JL CHERMANT *et all.* [13-14-15]. FERRAZ-SHAWMUT also carried out studies with help from high-school laboratories [16-17-18].

The method of characterization consists in three steps :

1. preparation of the sample,
2. SEM-micrographs and picture-treatment,
3. mathematical analysis.

3.3.1. Preparation of the sample :

Sand-cores are compacted in containers (in fact ceramic fuse-bodies) and then agglomerated with water-glass according to the usual industrial manufacturing-process. As made, sand cores present a porosity and their cohesion is not sufficient for any further mechanical operation. It is the reason why, the core is impregnated with a epoxy resin. Impregnation allows the core to be cut and polished without risk of breaking. Note that, for the time being, no fuse element are added to sand-core.

3.3.2. SEM-micrographs and picture-treatment :

The samples are observed by back scattering electrons microscopy. In comparison with optical microscopy, this method allows to improve the contrast between the two phases, i.e. silica and resin.

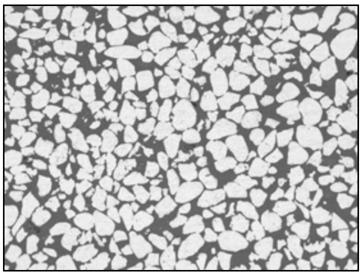

Fig.5 : SEM-micrograph.

Afterward, the quality of the picture is not sufficient to proceed to mathematical analysis. The first SEM-picture has to be transformed into a binary picture, with only black or white spots.

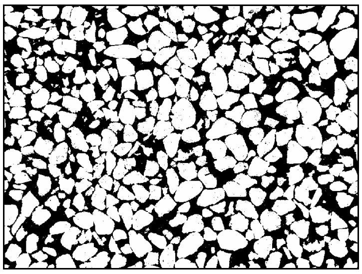

Fig.6 : binary picture.

And then, grains have to be separated from each others. Filtering and thresholding of the binary picture are necessary to get a workable picture from the point of view of mathematical analysis. An algorithm for automatically partition of phases has been used. Unfortunately a final "manual" operation cannot be avoided.

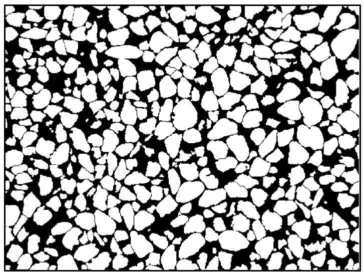

Fig.7 : pictures with separated grains.

3.3.3. Mathematical analysis:

Anybody could believe that the distribution of the grain-sizes will be homogeneous inside a container. But, with a minimum of consideration, it will appear that from the bottom to the top of the container, maybe will occur some segregation between big and large particles. In fact, reality is out of this evidence and we can observe clusters or lines of particles of comparable sizes.

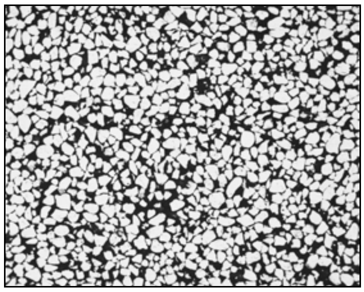

Fig.8 : SEM-micrograph showing clusters of big grains and clusters of little ones.

Hence, it is very interesting to go further from the simple compacity for characterizing the grain-arrangement. What is generally proposed is to consider following parameters :

- length between intercepts (intercepts are counted along a line, each time that the line goes inside a grain).

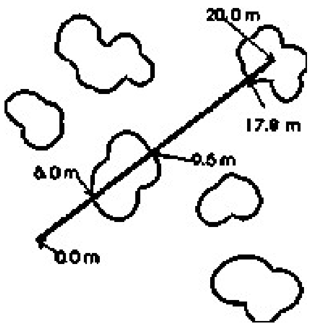

Fig.9 : Definition of intercept. Along the line, we meet two inputs in the grains, i.e. two intercept. Distance between these two intercepts will be considered.

- surface-ratio of the grains to the total area,
- quantity of objects per surface-unit.

Just considering the length of intercepts (or the surface-ratio, or the number of objects) is not sufficient, even if statistical calculations such as mean value, standard-deviation or distribution-curve are done.

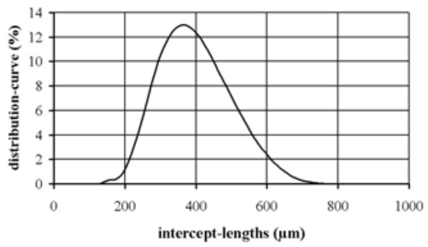

Fig.10 : usual distribution-curve for intercept-lengths.

Solution is to carry out a standard-deviation-analysis. It consists in calculating the value of the parameter on sub-areas, all sub-areas constituting a partition of the total one. All the values measured on the sub-areas are used for calculating a mean and a standard-deviation. By making variations of the size of the sub-areas, we get the curve of the standard-deviation versus the size of the sub-areas.

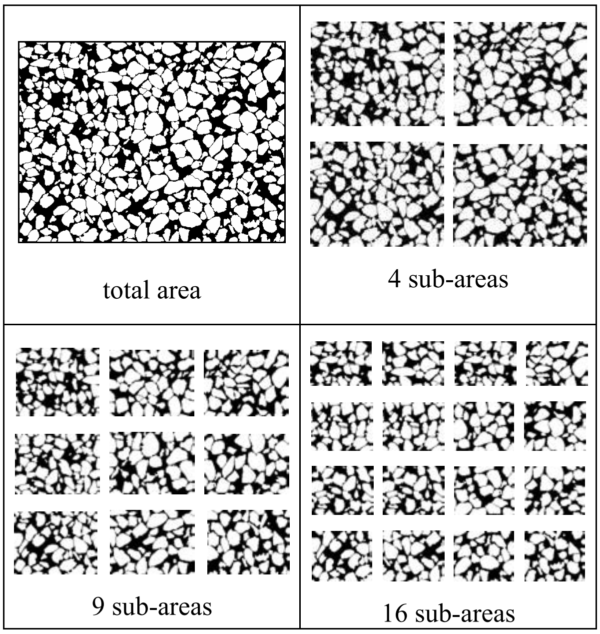

Fig. 11 : Principle of the successive sharing of the total area to sub-areas.

Standard-deviations (or variances) are then plotted versus the size of the sub-areas. That gives curves which are characteristic of the arrangement of the grains within the sample.

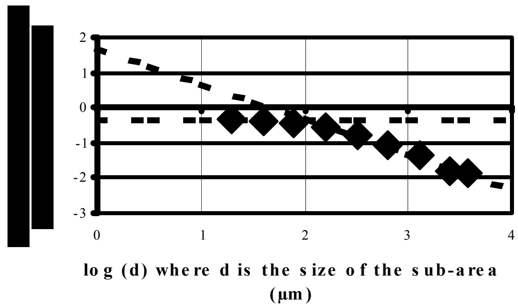

Fig. 12 : Curve of the standard-deviation-analysis for surface-area.

3.3.4. Comments:

Let us consider the parameter "surface area". See fig. 12.

For low sizes of sub-areas, standard-deviation doesn't depend on the size of sub-area. It just depends on the global porosity of the sample.

For bigger sizes of sub-areas, it is possible to demonstrate that standard-deviation is as the inverse of the size.

The curve is composed with two linear parts. Crossing of the two lines is a characteristic point called the "range of the curve".

Let us now have a look to the same analysis-curve for intercept-lengths.

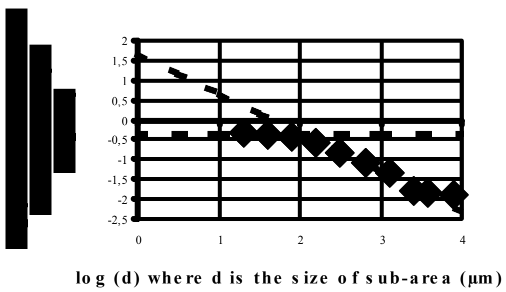

Fig. 13 : Curve of the standard deviation-analysis for intercept-lengths.

Evidence is that we find again some identical lines, but for the very largest sub-area sizes, a new flat stage appears.

The interpretation of this is that the parameter "surface-area" is constant over the all global surface, but the parameter "intercept-length" may vary from one region to the other one of the global area. It is a "measure" of the clusters of big and little grains.

4. Conclusions

FERRAZ-SHAWMUT is continuously tending to improve the quality and the performances of its products. For example, many adjustments of the sanding process are carried out in order to get the better and the more reliable electric characteristics. The problem is that between input-parameters, i.e. manufacturing-parameters and output-parameters, i.e. results of electrical tests, there is a lack of possible observations.

Standard-deviation analysis is a way to observe the arrangement of the grains. Of course this is still a heavy method, but it can be, with a minimum of improvements, very helpful for a better understanding of the operation-phenomena and for any modelling.

References

[1] Saqib M.A., Stokes A.D., Seebacher P.J. "Pressure inside the arc channel of high-voltage fuse" *ICEFA* Torino 1999.

[2] Saqib M.A., Stokes A.D., James B.W., Falconer I.S. "Arc temperature measurement in a high-voltage fuse" *ICEFA* Torino 1999.

[3] Lipski T., "Generation and propagation of the pressure due to the fuse-element disintegration in H.B.C. fuses" *Proc. of the Conf. on Gas Discharges and their Applications - Oxford, IEEE Conf. Pub, pp 87-90,* 1985.

[4] Wolny A., "Effect of fuse element confinement on the rate of rise of fuse arc ignition voltage" *ICEFA* Torino 1999.

[5] Gnanalingam S., Wilkins R. "Digital simulation of fuse breaking tests" *IEEE proc. Vol. 127, nr 6, pp 434-440* 1980.

[6] Bussière W., Bezborodko P., Pellet R. "Spectroscopy study of cutting electrical arc in H.B.C. fuse" *ICEFA* Torino 1999.

[7] Bussière W., "Influence of sand granulometry on electrical characteristics, temperature and electron density during high-voltage fuse arc extinction*" J. Phys. D:Appl.physs. ,34, p 925-935,* 2001.

[8] Murin-Borel V., Lieutier M., Parizet M.J. "Electric field and pressure measurements in high voltage fuses" *ICEFA* Torino 1999.

[9] Rochette D., Clain S. "Numerical simulation of Darcy and Forchheimer force distribution in a H.B.C. fuse" *Transport in Porous Media, 53, pp 25-37,* 2003.

[10] Rochette D. "Modélisation et simulation de la décharge d'un arc électrique dans un fusible moyenne tension", *Thèse de Doctorat en Physique, Université Blaise Pascal Clermont-Fd,* 2002.

[11] Vivier G., "Relations entre la microstructure des blocs agglomérés et les propriétés électriques des fusibles", *Thèse de Doctorat, INSA Lyon,* 2000.

[11] Serra J., "Images Analysis and Mathematical Morphology" *Academic Press* 1982.

[12] Serra J. "Image Analysis and Mathematical Morphology vol.2 : theoretical advance", *Academic Press* 1988.

[13] Coster M., Chermant J.L. "Précis d'analyse d'images" *Les presses du CNRS* 1985.

[14] Boitier G., Chermant J.L., Chermant L., Doireau F. Vicens, J. "Morphologie par analyse d'images de composites à fibres longues : principes et résultats", *in La Revue de Métallurgie*, Dec. 1977.

[15] Coster M., Chermant J.L. "Image analysis and ceramics" *in La Revue de Métallurgie* Feb. 2000.

[16] Gelet J.L., Missiaen J.M. "Le rôle du sable dans les fusibles ultra-rapides » *Congrès Matériaux SF2M Tours* 2002.

[17] Acevedo D., Missiaen J.M., Gelet J.L. "Caractérisation d'agglomérés de sable pour fusibles de puissance" *Proc. De la poudre au matériau massif Albi* 2003.

[18] Roueche E., Thomas G., Perier-Camby L., Seris E., "fragmentation de grains de sable. Suivi par émission acoustique et bilan de population" *Proc. De la poudre au matériau massif Albi* 2003.