

MATERIALS ANALYSIS OF USE OF PVC TUBES IN SOLAR COLLECTORS

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Abstract *This paper presents a study of the inherent degradations of PVC tubes due to the thermal effect and ultraviolet solar radiation. The approach relates its causes and its effect of use of the PVC tubes as elements to absorption, forming a coil, in solar collectors for water heating. It is demonstrated that such degradations can be burst through the use of an outflow and an appropriate regimen of work, as well as of a protective layer for the tubes, in this case black ink used to magnify its absorption. The results of the properties of tubes that had been exposed to the degradation effect for up to five years are presented. The viability of use of this type of collector is demonstrated through comparative analysis of tubes exposed and not exposed to the sun, concluding for the low cost, easy assembly and maintenance of the system.*

Keywords *thermal degradation, UV - degradation, element to absorption of PVC*

1. INTRODUCTION

In a solar collector with PVC tubes, the first question that arises is about its degradation. Specialized literature show that the susceptibility to the thermal degradation of PVC reaches a critical level from temperature above 60°C in its surface. Another type of degradation due to ultraviolet radiation (UV) also represents a restriction to the use of solar collectors with PVC tubes (Mano, 2000, Souza, 2002). Given that the cost of the PVC tubes well less expensive than copper, we developed, constructed and studied, in the Solar Energy Laboratory of Federal University of Rio Grande do Norte, two types of alternative solar collectors with absorption coils of PVC tubes, the wing and labyrinth collectors shown in figure 1. The study demonstrated the thermal viability of these collectors, which work in regimen of continuous stream, with only one pass of the fluid for the inward of the same ones; previous works were published (Souza, 2000, 2002, 2004, 2006).

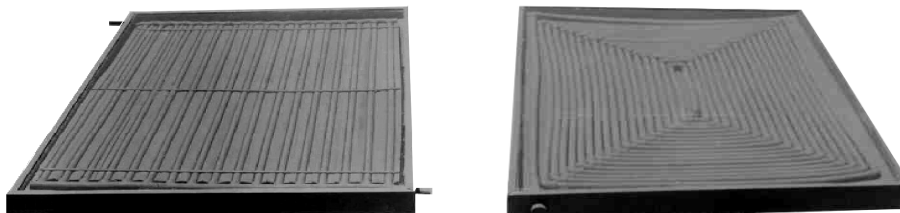


Figure 1. The wing and labyrinth collectors.

The changes of the mechanical properties of the PVC tubes, exposed to the sun for periods of one year, three years and five years with and without painting were studied. In these studies, the baseline was a PVC tube that was neither exposed to the sun, nor crossed by a hot fluid. We determined the properties of traction, compression, bend and impact. All the analysis is comparative to the tube that was never exposed to the heat and solar radiation, and will be expressed through a factor that relates the property of the sample with of the standard tube.

2. LITERATURE REVIEW

Although the degradation of polyvinyl chloride has been well studied, there is much controversy, which needs to be cleared. Some mechanisms of the degradation were proposed with base on various experimental works.

Fisch, in 1999 has shown that the polyvinyl chloride thermal degradation is the result of a "zipper dehydrochlorination" process that involves allylic chlorides as intermediates and is catalyzed by hydrochloric acid.

Yarahmadi, in 2001, also demonstrated that this type of degradation is critical during the process of manufacture of PVC, when the same casting and after that it is extruded. The degraded polymer loses its plasticity, passing to a rigid composition. Despite the sensitivity that the PVC presents in relation to the heat, it is easily processed with the composite that will give its ideal composition.

Petre, in 1999, accepted that a first degradation process which occurs at lower temperature, consist mainly of dehydrochlorination either with initiation at the defects polymeric chain (double bonds, tertiary and allylic chlorine, branching, etc or by random initiation in any point of the chain.

Additives as stabilizers, lubricants, loads and pigments are used to inhibit the processes of thermal and for ultraviolet solar radiation degradation also making it easier the processing of PVC. The stabilizers are very important products, because they inhibit the degradation of PVC. They enhance the thermal stability of polymer, giving it conditions to support the heating that the process requires. These products can react with hydrochloric acid (Benaniba,2001, Jordan,2001).

For this type of collector to became competitive, it is also necessary a study about the relative degradations, that is related to the useful life of the considered archetype.

It becomes imperious then to establish if the display to the sun of the PVC tubes inherent to the process of attainment of thermal energy, cause the level of degradation related by Torikai in 1999, in that it says respect the display to the ultraviolet radiation and the levels of temperature above 60oC.

An important aspect of the use of the PVC tube as absorption element in a solar collector is the fact paints it of black color ink. This film creates a protective layer in the tube, protecting it against UV. However, this same film provokes a temperature increase in the tube, making it more susceptible to thermal degradation.

We focused in the study of available tubes in the market, trying to create conditions to making it thermal absorber, without reaching degradation level.

Sullivan, in 1999 and Ragab,in 2001, indicated that the thermal and for UV degradations, induce fragility to the material, but the quantification of these levels of degradation is not available. Jordan²⁴, proved that this embrittlement could be translated by the loss of mass or through the loss of hydrogen chloride and the consequent sprouting of double bonds.

Since a manufactured tube available in the market was used the temperature levels that will be submitted the tubes to absorption will be well lesser of that inherent to the manufacturing process. The degradation combat through the increase of the percentage of chlorine was not used, which take neither place in the CPVC, nor addition in bigger ratio of stabilizers. We decided to try hinder that such tubes reached the temperature of thermal degradation.

3.EXPERIMENTAL PROCEDURE

The thermogravimetric (TG) measurements were taken in order to determine the loss of mass, when the tubes were exposed to solar radiation, sampling 1,301 mg of PVC, with five years of exposure to the sun, submitting the sample to a temperature range of 0 - 600o C, at a rate of 5.0oC/min of heating.

In order to evaluate the behavior of the PVC of tubes exposed to long periods of solar radiation, some compared properties had been determined and than a factor () that relates the property of the sample in the study to the properties of the standard sample. Tests of t traction, compression, bend and impact, in the five samples of the each type studied, were carried out, to analyze the levels of associate to thermal and UV degradations and evaluate its causes and effects (Souza, 2002).

To analyze the microstructure of degradation of the tubes submitted to the action of the solar rays a scan electron microscope was used. The samples were analyzed in its internal and external surfaces.

Five samples of standard tubes (NS) were submitted to one year (1YBP), three years (3YBP, 3YWP) and five years (5YBP, 5YWP) of sun exposure, with and without black color film.

4. Results and Discussion

4.1. Thermogravimetric Analysis

Figure 2 shows a curve of TG for the sample of PVC tube with five year of sun exposure display to the sun, with black film, without circulating fluid.

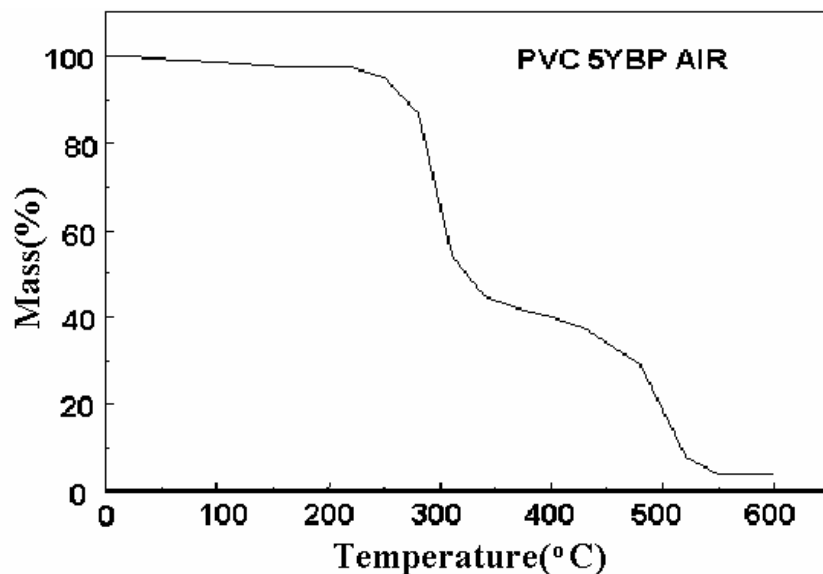


Figure 2. Data of the thermogravimetric analysis.

The results of this analysis give evidence of that the more significant loss of that takes place for the range of corresponding temperature 223oC – 370oC, with one loss of about 55%. For the temperature of 600oC the mass trash that remains corresponds to 3,9 % approximately. In the range of inherent temperature the use of the PVC as element to absorb radiation in a solar collector, the level of loss of mass is insignificant, with one loss of about 2%.

4.2. Mechanical Properties Measurements

The data of the relative comparative parameters (δ) raised for the tensile, compression, bend and impact tests are shown in the Table 1 and Table 2. Table 1 shows the parameters of the traction and Table 2 the values of traction, compression, bend and impact resistance.

Table 1. Values of relative to the parameters the traction tests, where δ_{TS} , δ_E , δ_{YS} , δ_{PD} and δ_{ED} are the comparative mean parameters of tensile strength, of modulus of elasticity, of yield strength, of plastic deformation and of the elastic deformation.

TYPE	δ_{TS}	δ_E	δ_{YS}	δ_{PD}	δ_{ED}
NS	1.00	1.00	1.00	1.00	1.00
3YWP	0.95	1.04	0.81	0.27	0.75
5YWP	0.95	1.1	0.86	0.24	0.78
1YBP	1.08	1.15	0.99	0.13	0.82
3YBP	1.11	1.15	1.00	0.10	0.98
5YBP	1.15	1.15	1.07	0.09	0.98

Table 1 shows an increase of up to 15 % in the tensile resistance; an increase of 15 % in the modulus of elasticity; an increment of 7 % in the yield strength, an extremely significant reduction in relation to plastic deformation, above of 90 % and a small reduction in relation the elastic deformation for sample 5YBP, the one that was more displayed to the sun. The higher level of absorption radiation results in an increase of rigidity of the samples exposed to the sun during a long period, the same as the ones spotted of black color ink.

Table 2. Mean comparative parameters of the raised mechanical properties, where δ_{TS} , δ_{CS} , δ_{BS} and δ_{IE} are the average relative comparative parameters of the traction, compression, bend and impact.

TYPE	δ_{TS}	δ_{CS}	δ_{BS}	δ_{IE}
NS	1.00	1.00	1.00	1.00
3YWP	0.95	0.99	0.98	0.52
5YWP	0.95	0.96	0.98	0.52
1YBP	1.08	1.10	1.08	0.42
3YBP	1.11	1.09	1.06	0.42
5YBP	1.15	1.16	1.08	0.32

One perceives clearly that the property more affected by the exposure of the PVC tubes to radiation, with consequent increase of temperature in function of black color, is the impact, in accordance to Sullivan22 and Ragab23, with a reduction in its energy for rollback of 68% for the sample spotted of black color exposed to the sun for five years. The tensile resistance had an increase of 15 %, 16 % in the compression resistance, 8 % in the bend resistance, of the tube that was exposed to the sun and painted of black color, passed exposed more time, compared to the standard.

4.3. Micrographs Analysis

The figures 3 and 4 show the micrographs carried through with a scan electron microscope, for the samples that had been exposed more time, 5YWP and 5YBP and the standard samples, NS. The section titles and subtitles must be aligned at left, typed with Times New Roman, size 10, bold style font. They must be numbered using Arabic numerals separated by points. No more than 3 sublevels should be used. One single line must be included above and below each section title/subtitle.

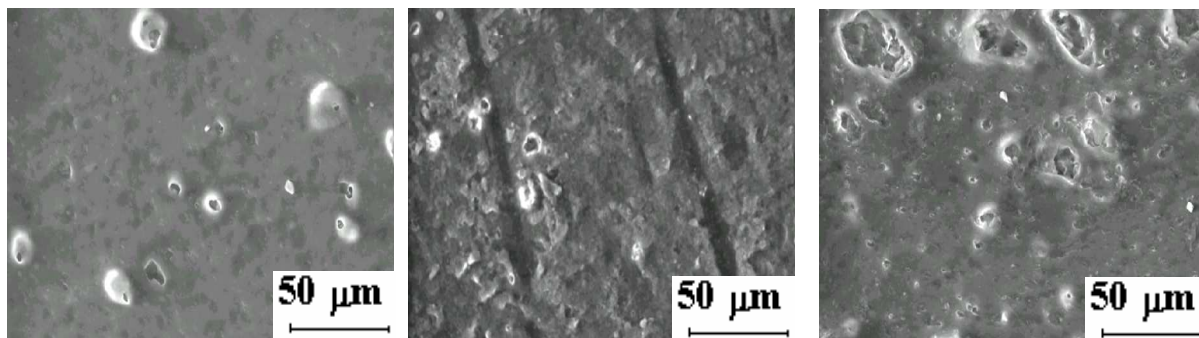


Figure 3 - SEM micrograph of the internal surfaces of the samples for (a) NS, (b) 5YWP and (c) 5YBP.

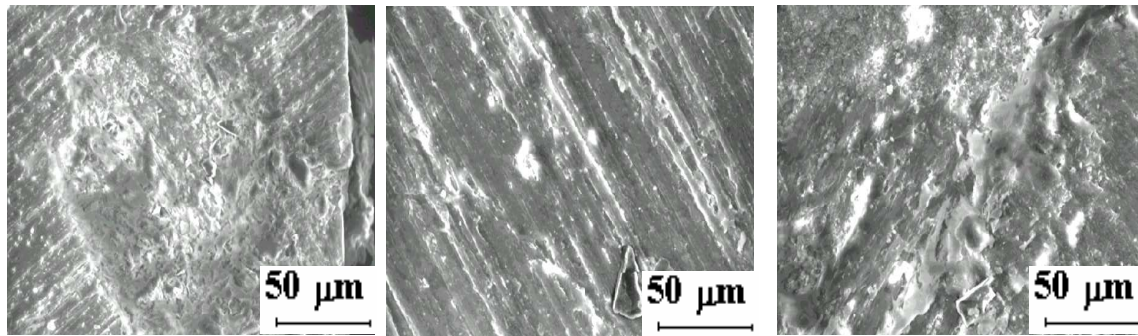


Figure 4 - SEM micrograph of the external surfaces of the samples for (a) NS, (b) 5YWP and (c) 5YBP.

The analysis of the micrographs shows that the type of degradation for the samples that had been exposed without painting is different to those presented by the samples that had been covered with black ink. The micrographs confirm the inherent degradations of PVC tubes exposed to the action of the solar rays, and shows differences between degradation for UV, higher level in the tubes not spotted, and predominant thermal degradation in the painted tubes.

The types of degradation reveal different forms: for UV, through cracks and thermal for multipunctual defects ones, both in the microstructure. By rough estimate naked was not evidenced the occurrence of fractions, cracks, punctures or other types of defects, that compromised the use of the PVC tubes as elements for the absorption of radiation.

5. CONCLUSIONS

1. The process of degradation of PVC tubes when submitted to the heat and exposed to the solar rays is clearly observed. The thermal degradation is higher than UV degradation. This thermal degradation does not produce loss of mass in the tube, being carrying the fragility of the same associate to the sprouting of double bonds when the process of unfastening of HCl of the main string.

2. The impact test is the one that better it translates the level of fragility as a function of the time of exposure to the sun, demonstrating that such level reaches significant values for the samples with bigger time of exposure in relation to the standard.

3. Despite of evidence of the fragility level being sufficiently intense, in relation to the impact, such request does not occur in the work condition.

4. The levels of temperature of the tubes of the coil do not reach the critical level in regard to thermal degradation. Therefore it is possible to use a plastic tube, characterized as a thermal insulator, as a conductor of heat, capable to promote the heating water.

5. The properties of traction, compression and bend resistance to exposed tubes spotted of black ink are increased.

6. It is important to point out that the analyzed samples had been submitted the much more critical conditions than the tubes that compose the absorption coil of a collector. The exposed tubes that had bigger time of sun exposure had not presented cracks, holes or another type of attack. Therefore, it shows that the time of useful life of a collector that uses PVC tubes as elements of absorption will be sufficiently long.

7. The PVC tubes show thermal, material and economic viability of use as elements of absorption in solar collectors. Such collectors can be produced to a lesser cost than the conventional collectors, which use tubes of copper, presenting cost of manufacturing of U\$50/m², which represents 60% of the price of the conventional collectors.

6. REFERENCES

- Benaniba, M.T.; Belhaneche-Bensemra, N.; Gelbard, G. Stabilizing effect of epoxidized sunflower oil on the thermal degradation of polyvinyl chloride, *Polymer Degradation and Stability*, v. 74: (3), p. 501-505, 2001.
- Fisch, M.H.; Bacaloglu, R. Mechanism of polyvinyl chloride stabilization, *Plastics Rubber and Composites*, v. 28: (3), p. 119-124, 1999.
- Jordan, K.J., Suib, S.L.; Koberstein, J.T. Determination of the degradation mechanism from the kinetic parameters of dehydrochlorinated polyvinyl chloride decomposition, *Journal of Physical Chemistry B*, v. 105: (16), p. 3174 - 3181, 2001.
- Mano, E.B. *Polímeros como Materiais de Engenharia*, Editora Edgard Blucher, São Paulo, 2000.
- Petre, A. L.; Budrugaec, P.; Segal, E. Thermal Degradation of Polyvinyl Chloride, *Journal of Thermal and Calorimetry*, v. 56, p.1065-1070, 1999.
- Ragab, A.R.; Alawi, H. Weathering effects on the fracture properties of polyvinyl chlorine pipes, *Journal of Testing and Evaluation*, v. 29: (1), p. 44-49, 2001.
- Souza, L.G.M. *Sistema Alternativo de Aquecimento Solar*, CONEM - Natal/RN, 2000.
- SOUZA, L.G.M., Análise comparativa entre coletor solar plano convencional e coletor solar alternativo composto por múltiplos tubos de PVC, IV CONEM – Congresso Nacional de Engenharia Mecânica, Belém - PA, 2004.
- SOUZA, L.G.M., Coletor solar não convencional, de baixo custo, composto por múltiplos tubos absorvedores de PVC, IV CONEM – Congresso Nacional de Engenharia Mecânica, Belém - PA, 2004.
- Souza, L.G.M., Gomes, U.U., 2002, Viabilidades térmica, econômica e de materiais da utilização de tubos de PVC como elementos absorvedores em coletores de um sistema de aquecimento de água por energia solar, Tese de Doutorado do Programa de Doutorado em Ciência e Engenharia de Materiais, UFRN.
- SOUZA, L.G.M., Sistema de aquecimento solar de agua para aplicações residenciais utilizando materiais alternativos, V CONEM – Congresso Nacional de Engenharia Mecânica, Recife-Pe, 2006.
- Souza, L.G.M.; Gomes, U.U. Coletor Solar em Labirinto com Tubos Absorvedores de PVC, CONEM - João Pessoa/Pb, 2002.
- Souza, L.G.M.; Gomes, U.U. Coletor Solar Multitubos de PVC Aletado com um Novo Modelo de Configuração em Série, CONEM - João Pessoa/Pb, 2002
- Souza, L.G.M.; Gomes, U.U. Sistema Alternativo para Aquecimento de Água utilizando Energia Solar, CONEM - João Pessoa/Pb, 2002.
- Sullivan, F.R.; Elleithy, R.H.; Abu-Ali, A. Effect of thermal degradation on the impact properties of PVC compounds, *Journal of Vinyl & Additive Technology*, v. 5: (4), p. 200-204, 1999.
- Torikai A.; Hasegawa, H. Accelerated photodegradation of polyvinyl chloride, *Polymer Degradation and Stability*, v. 63: (3), p. 441-445, 1999.
- Yarahmadi, N.; Jakubowicz, I.; Gevert T. Effects of repeated extrusion on the properties and durability of rigid PVC scrap, *Polymer Degradation and Stability*, v. 73: (1), p. 93-99, 2001.

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