IMPACT AND BALLISTIC EVALUATION OF POLYCARBONATE PROTECTORS FOR GLASS INSULATORS IN TRANSMISSION LINES

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Abstract. *This work evaluated the mechanical performance of polycarbonate protectors to be installed in high-voltage lines in order to protect the glassy skirt of electrical insulators against breaking by vandalism. The polycarbonate is a thermoplastic engineering material with excellent physical properties and can be used as raw material to manufacture the protective plates. The performance of this material was evaluated by impact test with a mechanical device for impact with a pendulum and the insulators were tested under strain stress with and without polycarbonate protection. Ballistic tests were also conducted, with different armors, in a shot stand using a 6mm polycarbonate protector. As a result of the laboratorial impact test, the required impact energy to break the glassy skirt with protector was more than two times bigger compared to the situation where the insulators were not protected with the polycarbonate. In ballistic test, projectiles from Magnum 44, equivalent to a rifle, could break until 3 glass insulators in chain when each insulator was protected with a protector. Laboratorial impact test with pendulum could reproduce the impact energy from ballistic experiment and the polycarbonate showed appropriated to be used to shield insulators and other devices, even under an electrical field condition.*

Keywords: *polycarbonate, impact, ballistic, glass, insulator, vandalism.*

1. Introduction

In general, a transmission line of 230 kV is isolated from the earth by glass or porcelain insulators in chain, placed in a vertical or horizontal position. Glass insulators are responsible for electrical insulation and mechanical hanging of electric cables in transmission lines. These insulators have a long tradition in Brazil and possess a useful life over than 40 years, but they are the most vulnerable elements of a line, due to the electromechanical loads nature that are submitted, to the action of the environment (sun, wind, water, pollution) and depredation. Glass insulators damages by vandalism are a national and world-wide reality and result in the glassy skirt breaking. Once is broken the insulator, there is no security for the hot line electricians during the maintenance and exchange of the damaged units, when the amount of remaining complete insulators in a chain is less than seven, in particular atmospheric conditions. The line's disconnections caused by vandalism imply in costs and expenditures for substituting the broken insulators and punishment applied by governmental entities. Because of the rigorous legislation in Brazilian electric segment, the increasing demand and the quality energy supply requirement, it is necessary to minimize the lines' disconnections caused by vandalism acts. Figure 1 shows a typical glass insulator for high voltage. The break of glass insulators in transmission lines by the vandalism represents about 75% of interruptions of energy supply, according to Chesf - Hydroelectric Company of San Francisco, Brazil. Avoiding damages on high voltage systems, polymeric insulators have been installed in transmission lines. Besides being more expensive than a glass or porcelain, polymeric insulators are prone to deteriorate and fail due to ageing by environment (sun, flashover, water, pollution, etc.). In order to minimize damages in glass insulators for transmission lines, protectors for insulators can be used to shield the glassy skirt against cracking, guarantying the integrity of the product. In this direction, this work has the aim to evaluate the impact strength of polycarbonate protectors, simulating the break of glass insulators by impact tests with pendulum and ballistic test.

1.1. The polycarbonate

In order to manufacture the protectors for glass insulators, the material must attempt some needs, like good impact strength (mainly from guns), good dielectric properties (arc resistance), self-extinguish fire, high temperature resistance, durability, environment resistance (against UV rays from the sun), low specific weight (in order to avoid overload on metallic structures of high lines), low cost, easily to be processed and manufactured, non-pollutant to environment neither toxic to human and also esthetic (light and discrete color). Due to these characteristics, the polycarbonate was chosen to develop the insulators' protectors. The polycarbonate (PC) is a well known engineer thermoplastic material with high molecular weight (Albuquerque, 1999) and it's widely used due to its excellent properties (mechanical, chemical, electrical), including transparency, high impact strength (up to 900 J/m, 250 times more resistant when compared to the tempered glass), hardness, UV stability, dielectric strength around 16 kV/mm, water and thermal resistance (Okamoto, 2001; Mano, 1996). The uses of PC, named due to the presence of carbonate groups in main chain, as seen in Fig. 2, include windows, security shields, contact lenses, automobile shields cars, etc. (Ramani and Ranganathaiah, 2000).

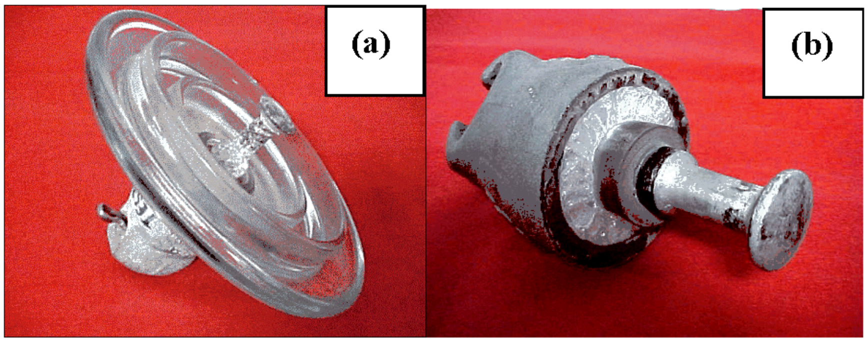

Figure 1. Photographs of a typical glass insulator for transmission lines. (a) Good glass insulator. (b) Broken glass insulator.

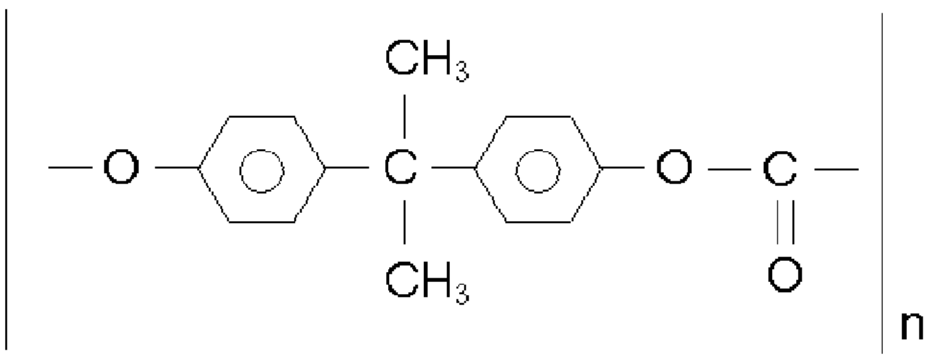

Figure 2. Structure of a polycarbonate monomer.

1.2. Impact and ballistic experiments to evaluate polycarbonate protectors

The impact test is a dynamic experiment, represented by measuring the absorbed energy before cracking, and the impact is obtained by a pendulum fall, with known mass and height, on the analyzed sample. The normalized tests (Charpy and Izod, for example) use samples with normalized dimensions. However, besides being used to compare different materials, normalized testes do not offer enough information about the performance of the whole product in use conditions (Garcia *et al.*, 2000).

As a consequence, to develop PC protectors and to evaluate its impact strength in order to protect the glassy skirt of insulators, two kinds of experiments must be realized. First, a laboratorial impact test with equipment specially designed and constructed by us may break glass insulators under strain stress, using a pendulum, which permits to estimate the impact energy of a general projectile. Second, a ballistic test using different types of guns and projectiles (with higher impact energies than that estimated in laboratorial experiment) may evaluate the protectors in a more severe condition, closer to a real vandalism act.

2. Materials and methods

2.1. Laboratorial impact test

The laboratorial impact test was conducted under certain conditions to simulate the break of the glass skirt by a general gun's projectile. Therefore, the energy of a projectile was estimated adopting the following hypothesis:

- Distance between shooter and target (insulator): 20m.

- Glass insulator length: 0.146 m.
- Length of a chain with 16 insulators (for 230 kV lines): 16 x 0.146 m ≅ 2.5 m.
- Minimum height of the insulator from the ground: 20m.
- Conservative system energy.
- Projectile's weight: 0.02 kg.
- Impact velocity of the projectile: 250 m/s.
- Gravity: 9.8 m/s².

By using the parameters above, the impact energy of a general projectile was determined around 650J. In order to obtain the maximum impact energy for the pendulum close to the projectile energy, using a pendulum with 2 kg in weight, the velocity must be upper than 30 m/s and this imply in a 60m height fall, which is unviable to construct in a laboratorial scale. Therefore, using a pendulum with 1.5m in length (which means a maximum height fall of 3 m), the impact velocity would be less than 10 m/s and the pendulum should be around 20 kg in weight to get the maximum impact energy of 650J. These values showed appropriated to design the equipment and to estimate the parameters for cracking the insulators with and without protectors, as obtained in a ballistic test.

The impact equipment is composed by two devices, designed and constructed by us, assembled in a hydraulic press with 30,000 kg in capacity:

- Strain device (Fig. 3): holds up to two glass insulators on the machine and changes the vertical force (applied by the hydraulic press into a horizontal force. This device simulates the load applied on insulators during the sustenance of the electrical cables and can vary the incident angle of the impact by rotation of its basis (0° to 75°).
- Pendulum device (Fig. 4): consists in a pendulum that impacts the insulators, from a known height. The point of the pendulum is threaded, permitting the use of different contact areas. Two points with 10 mm and 5mm in diameter were used in this experiment. The minimum mass of the pendulum is 9 kg and can be increased by placing halters on the pendulum.

Because the glass of the insulator is tempered, it scatters all directions when broken and for a safe use there are polycarbonate walls to avoid accidents during the experiment.

Colorless PC plates from different types and widths (3mm and 6mm for a compact type, and 4mm for an alveolar type) were used in this experiment. The protectors were made form these plates, which were cut in a square format of 300 mm side, with a central hole of 35mm in diameter to be placed in the insulators' pins. The experiment was conducted at room temperature (around 25°C), using ten good insulators. All the parameters of the experiment, impact angle, width of the protectors, impact energy (as a function of the pendulum weight and height of fall), side of the impact on the insulator (above or under the skirt) and contact area (diameter of the pendulum point), are given in Tab.1.

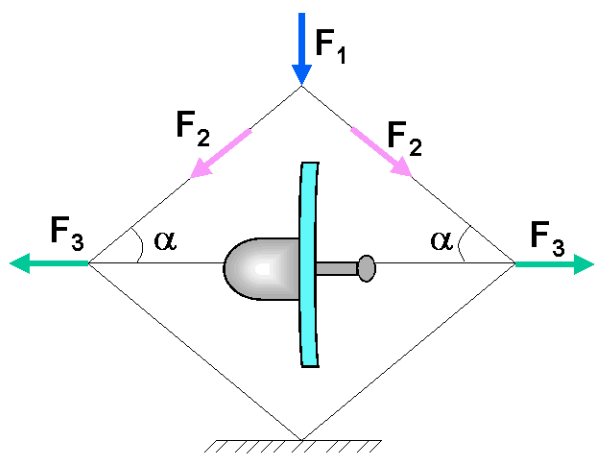

Figure 3. Draw of the strain device using one insulator. The vertical force in converted into horizontal force, which means that the compression stress applied by the machine changes to strain stress on the insulator.

Table 1. Parameters used in the impact test with the pendulum.

Impact angle		45°
Type of polycarbonate		Compact (3 mm) Compact (6 mm) Alveolar (4 mm)
Impact energy	Pendulum weight	21 kg
	Height fall	0,75 m to 2,50 m
Side of the glass skirt of the insulator to be impacted		Inferior (grooves)
Pendulum point diameter		5 mm 10 mm

2.2. Ballistic test

The ballistic test was conducted in a shot stand at Caxangá Golf Club, Recife (Brazil). A chain of five good glass insulators was used in this test, horizontally held in a metallic basis constructed by us. Only protectors made from compact PC type of 6 mm in width were used due to the good performance of this type at laboratorial impact test with the pendulum. Five protectors were placed in each insulator of the chain.

The distance from the shooter to the target (insulators) were around 15 m. The armors tested were: 0.38 caliber revolver, 0.38 caliber Glock, 0.45 caliber Glock and 0.44 caliber Magnum (this one is equivalent to a rifle). The experiment was realized in order to shot only the first insulator of the chain. To each armor, the damages caused on the protectors and the integrity of the insulators were observed between a shot and another, but none of the protectors neither the insulators were exchange until the end of the test. After the break of the first insulator, the test was continued until the break of the second insulator and so forth until the break of the whole chain or until the crack limit obtained by the armor.

3. Results and discussion

3.1. Laboratorial impact test

Figure 4 and Tab.2 present the results of the impact test with pendulum. The impact energy values were obtained by potential energy and indicate the impact strength offered by the protectors under different conditions. Among all of the configurations tested, the worst configuration was the insulator without protection, which impact energy was 205.80 J and 154.35 J, with 10 mm and 5mm point diameter respectively. By placing protector on insulator, the impact energy increase, i.e., the more difficult is to break the insulator. The alveolar PC (4mm) showed the worst impact resistance (205.8J) compared to compact PC (6 mm) presented the best value (514.5 J), using a 10mm pendulum point in both cases. Even using the 5 mm point the impact strength still is better from 6mm compact type PC (411.60 J). The 3mm compact type PC presented better performance than the alveolar type, however the 6mm compact type has about 28% to 40% more impact energy than the 3mm type, depending on the point size.

Table 2. Results obtained in the impact test.

Diameter of the pendulum	Protector	Weight of the pendulum (Kg)	Height fall of the pendulum (m)	Impact energy (J)
10mm	None	21,00	1,00	205,80
	PC alveolar 4 mm	21,00	1,50	308,70
	PC compact 3 mm	21,00	1,80	370,44
	PC compact 6 mm	21,00	2,50	514,50
5mm	None	21,00	0,75	154,35
	PC alveolar 4 mm	21,00	1,00	205,80
	PC compact 3 mm	21,00	1,20	246,96
	PC compact 6 mm	21,00	2,00	411,60

3.2. Ballistic test

The results of the ballistic test show that the compact PC protector, in 6mm of width, presented good performance against shots form different armors. The material avoided the break of the glassy skirt of the insulator when a 0.38 caliber revolver was used. The first insulator was broken when the Glock was used. Using 0.44 caliber Magnum the projectile only crossed three protectors and broke the third insulator. Even giving successive shots on the chain, no more insulators could be broken (the limit of break is then three insulators). These results are given in Tab.3 and Fig. 5.

4. Conclusions

The results of both tests, impact with pendulum and ballistic, are qualitative tests. However, there are complementary techniques to evaluate the protection offered by the polycarbonate material used as a shield for insulators and other applications, once the own product has been tested and the energy impact experimentally obtained simulate the real values from the ballistic test.

The polycarbonate, in the width of 6mm, presented as an appropriated material to be used as insulators' protector and other devices that need to be armored.

(a)

(b)

Figure 4. Photographs of the equipment constructed for laboratorial impact tests. (a) Without haters and before pendulum. (b) With halters and after the pendulum falling and insulator cracking.

Table 3. Integrity of protectors and glass insulators after ballistic test.

Protector	Armor	Result (maximum cracking)									
		Insulator #1		Insulator #2		Insulator #3		Insulator #4		Insulator #5	
		Protector	Glass	Protector	Glass	Protector	Glass	Protector	Glass	Protector	Glass
None	0.38 caliber revolver	---	Broken	---	Broken	---	Broken	---	Broken	---	Broken
6 mm compact type PC	0.38 caliber revolver	Punched	Entire	Entire	Entire	Entire	Entire	Entire	Entire	Entire	Entire
	0.38 caliber Glock	Punched	Broken	Entire	Entire	Entire	Entire	Entire	Entire	Entire	Entire
	0.45 caliber Glock	Punched	Broken	Punched	Broken	Punched	Entire	Entire	Entire	Entire	Entire
	0.44 caliber Magnum	Punched	Broken	Punched	Broken	Punched	Broken	Entire	Entire	Entire	Entire

(a)

(b)

Figure 5. Photographs of the ballistic test. (a) Metallic basis to hold insulators. (b) Insulators cracked after using 0.45 caliber Glock armor.

5. Acknowledgements

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