

Comparison of Tests of Thermal Fatigue Carried Out in Laboratory with Tests Performed under Critical Environmental Conditions for a Vehicle

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ABSTRACT

Plastic components of a vehicle are strongly affected by external environmental conditions. High temperatures can damage the components, influencing the behavior of other parts of the vehicle. In this work, the influence of temperature and weather conditions of the plastic components is evaluated. Results of tests of thermal fatigue carried out in laboratory are correlated with thermal solicitations obtained under several critical environmental conditions. Weather maps from several regions of Brazil were evaluated in order to identify critical conditions, and a vehicle was submitted to these critical ambient conditions. Ambient temperature, solar radiation and temperature of the plastic components were measured and compared with solicitations currently reproduced in laboratory. The maximum temperature values achieved by the components were determined, allowing the critical evaluation of the materials used in the car. Also, the comparison between laboratory and field results permitted a revision of the current adopted.

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INTRODUCTION

During the process of developing an automotive project, the experimental phase is the stage where the product is tested and validated. At this phase there is a verification of the effectiveness and robustness of the product, system or component to assure a functional life through the whole use phase, made by the client. In the phase of experimental trials, the simulated evidences are necessary and strategic to reduce the development time of a component or system, as it should be tested and approved before going into production. The simulated evidences increase the reliability of the tests and reduce significantly the time and cost, since they have a better control over reproduction and measurement of the results, important factors in the quality of work. This work studies the vibration thermal fatigue simulated test used in testing vehicles. In the test, a car is placed in an acclimatized chamber and submitted to cycles of high and low temperatures, combined with specific incident solar radiation values. The vibration of the vehicle under several road conditions is also simulated. The thermal cycle, main subject

of this paper, influences and alters the mechanical properties of plastic materials.

The ambient temperature and the solar radiation are responsible for the higher variations in temperature of the vehicle plastic parts and, consequently, the most significant changes in thermo-mechanical properties of the used plastics. The evaluation of the influence of climate solicitations over the vehicle plastic components was done by measuring the ambient temperature, the solar radiation and the temperatures in the plastic components mounted on the vehicle. With the alterations of mechanical properties with temperature, we have the failures linked to the factors of thermal dilatation and deformation of plastic components.

Regions of Brazil were studied, with critical conditions for the systems and plastic components, which means that the extremes uses by the costumer were evaluated, under high temperatures, high levels of solar radiation and low rainfall rates. Other factors considered in the evaluation of critical conditions were the transmittance of the sky and the solar geometry used to predict the sun's position during a day or a season.

Subsequently, the values measured in field were compared to the parameters, obtained in tests performed in climatic chambers, allowing the evaluation of the standard used to evaluation of the vehicle plastic components.

LITERATURE REVIEW

Solar radiation is the most influencing climatic solicitation in the temperature of the plastic components of a vehicle, being responsible for levels of temperatures above the local temperature. In the absence of solar radiation, the vehicle tends to achieve thermal equilibrium with the environment.

The life of commercial plastics is dependent of photo-stabilizers, or even superficial protections, since in most automotive applications the plastic is exposed to inclemency and adverse conditions of temperature and radiation. Solar radiation has a spectrum with wavelengths that comprehend from 0 to 3 μm , that are able to heat a plastic body, or even to break the chemical bonds of this plastic [1].

According to Andrady et al. [2] this effect is more emphatic when the polymers are under the influence of high temperatures, because the plastic exposed to solar radiation changes its mechanical properties, which limits its useful life. The authors exposed a PVC sample to adverse conditions of solar radiation and temperature for a period of twenty-four months. Two samples of the same material were analyzed. One of them was kept in the city of Dhahran (Saudi Arabia), which has high average temperatures. The other one was placed in Florida (EUA), with lower average temperatures. It was observed that the first sample was reduced by 43% of the strength tension, while the second sample was reduced by 26%. It is clear, therefore, that this difference is explained by the effect of the difference of temperature between the two regions, not only the solar radiation.

Bureau e Denault [3] studied and compared the experimental method of thermal fatigue SPLASH (thermal shock) through fissures and triplets of a plate exposed to abrupt temperature changes with fatigue models using nonlinear finite elements.

Russell et al. [4] showed the effect of temperature and solar radiation combined with fatigue from the impact of locking and unlocking seat belts in vehicles, specifically in bolt with the possibility of detachment during a collision. The results of the studies resulted in a recall for vehicles produced between 1896 and 1991 in almost all Japanese automakers, being required changing the raw material of the locking system of closure, because of the quality of the material exposed to temperature, solar radiation and cyclic efforts.

Berrehili et al. [5] studied the criterion of fatigue in polypropylene through the propagation of fissures in traction and torsion with temperature variation. The authors used of S-N curves of traction and torsion, available in the literature, as function of the tension found in samples during traction and torsion tests, which were compared to experimental studies.

Nebojsa, Salahifar [6] altered the optical properties of a vehicle (transmissibility, absorptive, reflectivity), or even through filters in their respective spectra of solar radiation. When dealing with the automotive field, and more specifically with cars, it is intended to have a greater occupant comfort and a fuel economy.

Kimlin and Parisi [7] studied pellicles applied in the glassed areas of an automotive, evaluating the percentage of penetration of UV light inside the vehicle, through the glass with and without special protective pellicles. In experimental analysis between two vehicles, the authors obtained a reduction of seven times in the damage to polymer materials inside the vehicle. The results and studies have shown directions and trends to be followed over the years, to increase the quality, reducing the cost of the raw material used in plastic components used inside the vehicle

Other lines of research evaluate the use of pellicles in relation with the transmission of infrared rays in glasses [8]. These pellicles can be used in vehicles to reduce the transmission of solar radiation through glass and, consequently, to reduce the temperature inside the vehicle. Thus, it can increase the efficiency of acclimation system and, as a result of this, it economies fuel.

Mezrhab e Bouzidi [9] correlate the experimental data of temperature inside a vehicle, with the results provided by a mathematical model of combined radiation, convection and conduction of heat exchanges inside and outside the vehicle. Studies of the color of the vehicle and type of glasses have been investigated. The study shows values of temperatures in some components, and in the occupant conditions when the vehicle is parked or moving.

The internal and external finishes of low costs vehicles is made from thermoplastic polymers. Today, in Brazil each vehicle uses between 60 and 90 kg of thermoplastics, being 50% approximately in internal components, 20 % in external components and the remainder in other systems. This situation is quite different from that in the 80s, where the average application of plastics in domestic cars was less than 30 kg [10].

The plastics have considerable variations in their levels of temperature, usually between -30°C and 50°C , but they can reach 100°C , with the combined effect of solar radiation. It is necessary, therefore, to evaluate the behavior of thermoplastic materials under the combined action of mechanical efforts and heat.

The determination of the temperature in plastic parts is required as feedback during the definition phase of the raw material component, because the temperature can, for example, vary the elastic modulus of the material up to 300%, with a range of 50°C , which is normal for tropical countries. The polypropylene is an example, with 20% of mineral filler - PP 70.20 [11], a very useful material in finishing components in the automotive field. Besides the elastic modulus, it has thermo-mechanical properties of thermal dilatation and heat distortion under load.

The polymers can receive additives, like stabilizers, that improve their properties and alter its physical and chemical characteristics, confer resistance to acids, heat and sunlight. They can also receive pigments that give them color and tone desired [12].

The evidence of vibration thermal fatigue of body components on the vehicle [13] has signs of vibration that simulate the road and are applied to the vehicle, together with the thermal cycle, which simulates critical conditions experienced by the vehicle simulating actual conditions. The thermal cycle is the central part of this work.

The standard thermal cycle is realized in a climatic chamber, which is based in three stages, ambient, hot and cold, and is determined with parameters of the chamber in a given period of time.

Each 24-hour cycle has the three stages, which is repeated for several days and has to simulate the climatic conditions of the vehicle utilization, to test and approve the plastic components, ensuring their functionality and aesthetics during all the useful life of the vehicle. The parameters of the chambers used as inputs data have different responses and influence directly the temperature of vehicles plastic components.

METHODOLOGY

Weather maps of Brazil were evaluated in order to determine the most critical conditions of solar radiation, temperature and relative humidity. To evaluate these critical conditions, macro and micro climates of Brazil were studied; micro climates of selected regions. This study was based on the database provided by the meteorological seasons, measured during the period from 1969 to 1990. Average temperature data, maximum temperatures, rates of irradiation / solar radiation, rainfall and average rates of relative humidity were evaluated. Solar aspects of geometry were also considered, which means that calculations were performed by the positioning of the sun in relation to certain regions during the month, day or time. Local assessments, position of the vehicle relative to the sun, type of surface and static and dynamic conditions of the vehicle were considered and tested.

A vehicle was subjected to these critical conditions, and the influence of the parameters in the vehicle plastic conditions was evaluated. The measured parameters were temperature in some specific points of the vehicle plastic components, ambient temperature and relative humidity, temperature and relative humidity inside the car and incident solar radiation. The tests were performed under the conditions defined by climate studies, considering situations of the vehicle utilization. In order to verify the conditions of standardized norms, the results were compared with data from tests performed in controlled ambient inside a climate chamber.

108 points of measuring temperatures in the vehicle finishing plastic components were defined, considering its

history and experience during the development of plastic components. All points of measurements were instrumented with K-type thermocouples attached with a metallic band. The uncertainty of the thermocouples was $\pm 1,6^{\circ}\text{C}$. In this paper only the temperatures corresponding to the panel, the door and the bumper are presented.

For the tests in the field, first were defined two positions for the vehicle in relation with the sun, and then more positions with the car at rest, with the windows all closed, a condition considered the most critical in the temperature. Then, the tests were conducted with the vehicle moving, to evaluate the differences of temperatures in the plastic parts, in relation to the condition on rest, or even to define minimum and maximum temperature gaps, which will be compared with the vibration condition of the vehicle in test.

Later, the same instrumented vehicle was tested in the climatic chamber, used to test the vehicle and its components through simulated tests. The chamber has 5m of width, 7m of length and 5m of height, and is capable of reproduce temperatures ranging from -30°C to $+80^{\circ}\text{C}$, a solar simulator with a capacity of maximum radiation of 1.300 W/m^2 and electro-hydraulic actuators that reproduce and simulate the signals of a road. The uncertainties of the chamber for the ambient temperature and to the relative humidity are, respectively, $\pm 2^{\circ}\text{C}$ and $\pm 3\%$.

Tests were performed with the standard cycle and tests with variations of the parameters of the chamber, such as the time for each stage of the cycle, the ambient temperature and radiation rate.

The superficial temperatures were analyzed at each instrumented point, considering the various settings of parameters of the thermal cycle in the climate chamber and the vehicle position in the defined cities.

RESULTS AND ANALYSIS

The field tests were carried out during a 14 days period, through 1800 km, comprehending eight cities. The route was defined from analysis of data provided by the meteorological stations.

TEMPORAL ANALYSIS OF TESTS

The maximum temperatures and higher average temperatures at each measurement point are related to higher exposure to solar radiation. This is an important condition in terms of correlation of the outdoor and laboratory tests. The incident solar radiation is presented with the corresponding ambient temperature and the surface temperature of some components.

Figure 1 presents the temporal data of solar radiation for a full test in the field, where the ambient temperature inside the vehicle and the superior central dashboard temperature is evaluated in parallel with the climatic conditions, ambient temperature and solar radiation index.

Figure 2 shows the temperature outside the vehicle (green line) and the temperature inside the vehicle (red line) during