METHOD OF PAVEMENT EVALUATION IN SITES OF TRAFFIC ACCIDENTS FOR FORENSIC PURPOSES

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ABSTRACT

Although the macro-texture of pavements is an important factor for safe driving, especially on wet tracks and with speeds above 50km/h, this parameter is not even evaluated in traffic accident sites. This study analyses 103 traffic accidents taken place on three state roads located in the southern region of Brazil, in which 18 such accidents the average heights of the sand spot, a parameter used to evaluate the macro-texture (ASTM, 2001), were lower than the minimum value recommended by the National Department of Transportation Infrastructure (DNIT). The speed of the vehicles was calculated for such accidents, as well as the kinetic energies involved in the system. The results indicated that a better condition of the macro-texture of pavements would reduce by 6,67% and 18,57% the kinetic energies involved in the accidents, minimizing both the damage caused to the vehicles, and specially the lesions caused to the victims.

Keywords: highway safety; pavement condition; macro-texture; traffic accidents.

INTRODUCTION

Every year more than 1,3 million people die in car accidents, and about 50 million more are injured all over the world (Sany and Navin, 2004; WHO, 2009). Between 1990 and 2003 6 million accidents took place only on roads, resulting in 3 million injured people and 42 thousand casualties (Noyce *et al.*, 2005; National Highway Traffic Safety Administration [NHTSA], 2004, *apud* American Association of State Highway and Transportation Officials [ASSHTO], 2008). Pavements are responsible for approximately 30% of the accidents; North-American studies indicate that approximately 14% of all accidents with fatal victims happen on wet tracks (Pottinger and Yager, 1986; Kuemmel *et al.*, 2000, *apud* AASHTO, 2008). DNIT establishes minimum macro-texture values for asphalt pavement, which has direct influence on the tire-pavement adherence in speeds over 50 km/h, especially on wet tracks. The personnel responsible for providing assistance in accidents rarely have the technical knowledge and appropriate equipment for an adequate evaluation of pavement conditions. This paper interprets the data on macro-texture collected from 103 traffic accidents on three state roads in the southern region of Brazil, seeking to verify if there was an effective contribution of the pavement for the occurrence and the severity of the accident, as well as to propose an evaluation protocol that can be easily adopted by the agents who provide assistance to and analyses of accidents.

PAVEMENT MACRO-TEXTURE

Bernucci *et al.* (2008) state that macro-texture directly affects the adherence between the asphalt pavement and the rolling band of the tire of the vehicle, especially on speeds higher than 50 km/h and wet track. Soares and Micaelo (2011) also affirm that macro-texture is the most important characteristic of the pavement for the analysis of hydroplaning. Ong and Fwa (2008) also inform that pavements with closed macro-texture lead to hydroplaning taking place in low speed.

Macro-texture depends basically on the gradation of the aggregate that composes the asphalt mixture used on the rolling surface. This texture scale can be classified as being open (large aggregates) or closed (small aggregates)

The “sand spot” essay (ASTM, 2001) is the most commonly used in Brazil to evaluate the macro-texture of pavements. This essay consists of filling the empty spaces in the superficial texture of the pavement with a known volume of 25.000 mm³ ± 150 mm³ of clean and dry natural sand consisting of round granules, which go through a 0,3 mm sieve, but are retained in a 0,15 mm sieve.

The surface of the pavement is cleaned with a soft hand brush; the sand is spread out on the dry surface with the use of a spreading disc with a 60 to 75 mm diameter. The essay must be interrupted when tips of aggregates begin to show.

After that, the diameter formed by the sand circle is measured in three different directions, and the average is calculated. Having the value of the diameter, the average height of the sand spot is calculated by Equation 1; the values recommended by DNIT are those between 0,60 and 1,20 mm (DNER, 2000).

$$H_m = \frac{4V}{D_m{}^2 \pi} \qquad (1)$$

Where:
H_m = average height of the sand spot, in mm;
V = constant volume of sand 25.000 mm³;
D_m = average diameter of the sand circle, in mm.

VEHICLE SPEED

The calculations for the determination of the speed of the vehicles in the most common accidents, are divided into three components:

a) Deceleration of the vehicle, resulting from the attrition of the tires against the track (in some cases producing skid marks). The inclination of the pavement must be determined, as well as the value of the coefficient of dynamic attrition between the tires and the pavement. This component is calculated by the classic formulation of dynamics (Beux, 1996) (Equation 2):

$$Vf\,(km/h) = 3{,}6 \times \sqrt{2 \times g \times d \times (f \pm h)} \qquad (2)$$

Where:
g = action of gravity (9,81 m/s^2);
d = breaking distance (in meters);
f = coefficient of attrition between the tires and the pavement;
h = longitudinal inclination of the pavement on the location of braking.

The values of the attrition coefficients (f) between the tires and the pavements were determined by using a MEMS accelerometer (*Micro-Electro-Mechanical Systems)* manufactured by *Analog Devices*, model ADXL203E, duly connected to an Atmel microcontroller, model ATMEGA8-16PU.

b) Damages to the vehicle, that is, which developed speed resulted in the forces necessary to produce the deformations on the vehicle. When a vehicle is involved in an accident, a certain portion of the kinetic energy is converted to mechanical work for the production of damages.

The damage velocity can be calculated by the intensity of the damages, measured in a scale with a growing velocity scale module, for medium sized vehicles (automobiles), and the damages are subjectively classified as minor, moderate, severe and very severe (Table 1) (Aragão, 2011).

Table 1: Damage velocity (Vd) due to intensity of damages.

Intensity of Damages	Vd (km/h)
Minor	0/20
Moderate	20/40
Severe	40/60
Very Severe	Above 60

It is also possible to project the damage velocity, by the damages caused to the vehicle, visually comparing them with the results of impact resistance tests made by the automobile industry. The damages caused in the tests made by the vehicle manufacturers are organized in tables, considering the speed of the vehicle, the intensity and the type of deformation caused by the damages.

c) Exact final position of vehicle. Thus, by the principle of the conservation of the quantity of linear movement, it is possible to determine which was the amount of velocity used to take the vehicle to its resting position.

This principle results from Newton's 2^{nd} Law, also known as the "Fundamental Principle of Dynamics": *The application of a force on a body causes the temporal variation of the quantity of movement of that body*. In other words, this law infers that the application of a force on a body produces an acceleration to the same direction and sense of the force and of a module that is proportional to it.

When such external force that acts on a body is null, the conservation of the linear moment takes place, without variation according to time. Considering an isolated formed system, for instance, by two vehicles, in case no external force acts on the system, or in case the resultant of all external forces is null, the total linear moment will be constant, regardless of what is happening between the vehicles (Negrini Neto, 2003). Thus, in case both vehicles travel on a given trajectory on which the collision will take place, the linear moment of the system will be constant, according to Equations 3 and 4 (Negrini Neto, 2003).

$$\sum_{i=A,B} \vec{P}_i = constante \Rightarrow \vec{P}_A + \vec{P}_B = \vec{P}'_A + \vec{P}'_B \qquad (3)$$

Where:
$\vec{P}_A$ = quantity of linear movement of vehicle **A**, before the collision;
$\vec{P}_B$ = quantity of linear movement of vehicle **B**, before the collision;
$\vec{P}'_A$ = quantity of linear movement of vehicle **A**, after the collision;
$\vec{P}'_B$ = quantity of linear movement of vehicle **B**, after the collision.

That is:

$$m_A \vec{v}_A + m_B \vec{v}_B = m_A \vec{u}_A + m_B \vec{u}_B \qquad (4)$$

Where:
m_A = mass of vehicle **A**;
m_B = mass of vehicle **B**;
$\vec{v}_A$ = velocity of vehicle **A**, before the collision;
$\vec{v}_B$ = velocity of vehicle **B**, before the collision;
$\vec{u}_A$ = velocity of vehicle **A**, after the collision;
$\vec{u}_B$ = velocity of vehicle **B**, after the collision.

ENERGY INVOLVED IN THE ACCIDENT

According to Negrini Neto and Kleinübing (2012), the physical structure of a given vehicle involved in a traffic accident interferes in the intensity, the form and the variable depth of the damages. However, regardless of the vehicular structure, the authors claim that the intensity of the damages, and, by consequence, the gravity of the lesions on the occupants, are directly related to the velocity developed by the vehicle. In the study of traffic accidents, the kinetic energy, among the several modalities of energy, is the most important, since it considers the mass (vehicle and occupants) and velocity parameters, in its determination (Equation 5):

$$Ec = \frac{mv^2}{2} \qquad (5)$$

Where:
m = summation of the mass of the vehicle and occupants;
v = velocity of the vehicle.

By analyzing Equation 5, it is observed that the velocity of the vehicle significantly influences the increase or the reduction of the energy involved in the system, that is, the intensity of vehicular damages and lesions on the victims. Thus, even small reductions of velocity may result in important decreases in the energy in the system, positively impacting the severity of the lesions suffered by the victims.

CASE STUDY

103 traffic accidents that took place on PR-090, PR-323 and PR-445 State Roads were examined, all located in the State of Paraná, southern region of Brazil; the macro-texture of the pavement in each accident was evaluated. Out of them, 18 accidents took place in locations with values of sand spot height below the minimum recommended by DNIT (0,60 mm).

Determination of the area for analysis

a) With the presence of skid marks: in cases where there are skid marks, the longer length of such marks is taken as a reference value. The evaluation of the pavement is done, therefore, beginning with the area of probable impact (API) of the vehicles, and along the longer length of skid marks, and on both senses of transit of the road.

b) Without the presence of skid marks: when there are no apparent skid marks on the pavement, but the knowledge of the maximum speed permitted for such road (considering the type of vehicles involved in the accident), the inclination of the pavement and the coefficient of attrition initially measured at the API, it is estimated, by approximation, by using Equation 2, the length of the hypothetical skid marks that would be necessary to completely stop the vehicle; some examples are mentioned in Table 2 (level pavement). The evaluation of the pavement should be done, therefore, beginning on API, along the estimated length and on both directions of the transit of the road.

Table 2: Extension of evaluation of pavement beginning at API, on both directions. .

Maximum speed permitted (km/h)	Approximate extension of evaluation (m)
40	8,00
50	13,00
60	18,00
70	25,00
80	32,00
90	40,00
100	50,00
110	60,00
120	70,00

Moment of execution of essays

The adherence of the pavement varies according to time, especially due to traffic and climate conditions to which it is subjected. Therefore, when a traffic accident takes place, the evaluation of the asphalt pavement should be done as soon as possible after the accident.

Many times, during the process of assistance after a traffic accident, there are no technical conditions to measure the texture and the coefficient of attrition of the pavement, whether by the transit of vehicles and people, or by the climatic conditions at the moment and the time of accident (accidents at night, during rainstorms, etc.).

Therefore, the evaluations should be carried out under satisfactory technical conditions (during the day and without rain) within the shortest possible time after the accident, reason why all necessary equipment must be available for the immediate execution of the essays.

The hypothesis suggested for this paper is that measurements be carried out no later than 24 hours after the accident. As an example, in case an accident takes place in the early morning of a given day, the ideal situation would be that the measurements of texture be carried out during the morning of that same day, so that the essays be carried out without alteration of the conditions of adherence of the pavement.

Evaluation of Results

By means of Equations 1 through 4, as well as Table 1, the velocities of the vehicles involved in the accidents were estimated, in the real situations of each of the roads, that is, with the coefficients of dynamic attrition resulting from the actual state of the macro-texture on each location. After that, such velocities were recalculated, taking into consideration the coefficients of dynamic attrition obtained from ideal conditions, that is, on locations on each of the roads which presented values of sand spot height that were higher than the minimum recommended by DNIT.

Finally, by means of Equation 5, the kinetic energies involved in each of the accidents were calculated, in both real and ideal conditions, with the evaluation of the variation of kinetic energy in each of the 18 accidents (Table 3).

Table 3: Velocities and energies involved in the accidents studied.

Accident	Vehicle	Ideal Vel. (m/s)	Real Vel. (m/s)	Ideal Ke (J)	Real Ke (J)	∆Ke (%)
1	V1	21,01	21,70	207481,50	221313,60	6,67
	V2	22,95	23,70	263398,50	280958,40	6,67
2	V1	25,47	26,67	418484,89	458613,58	9,59
	V2	16,84	17,63	143211,68	156944,30	9,59
3	V1	13,05	13,95	83447,78	95368,90	14,29
	V2	22,48	24,03	338625,50	387000,58	14,29
4	V1	25,56	26,58	336473,19	363754,80	8,11
5	V1	27,81	29,29	382843,10	424798,51	10,96
6	V1	31,23	33,35	565566,12	645223,32	14,08
	V2	26,39	28,19	337807,35	385385,85	14,08
7	V1	22,43	23,93	311797,90	355103,16	13,89
8	V1	32,70	35,41	636414,33	746078,95	17,23
	V2	33,13	35,87	641970,72	752592,79	17,23
9	V1	19,85	20,77	228627,54	250254,47	9,46
10	V1	28,73	31,07	449743,37	526090,68	16,98
	V2	34,79	37,63	623314,06	729126,29	16,98
11	V1	22,34	23,68	351895,54	395279,92	12,33
12	V1	26,04	27,87	413620,99	473940,72	14,58
13	V1	28,84	31,33	455404,97	537312,34	17,99
	V2	30,45	33,08	458984,39	541535,54	17,99
14	V1	27,89	29,65	412158,91	466065,25	13,08
15	V1	27,43	29,47	417488,09	482169,35	15,49
	V2	29,62	31,84	465129,38	537191,68	15,49
16	V1	24,19	26,15	286683,52	335137,07	16,90
17	V1	18,34	19,97	171606,33	203476,08	18,57
	V2	24,44	26,62	295727,36	350648,15	18,57
18	V1	22,36	24,05	267455,92	309484,70	15,71

CONCLUSIONS

The results presented in Table 3 indicate that a better macro-texture of road pavement would reduce the kinetic energies involved in the accidents by 6,67% to 18,57%, thus minimizing both damages on the vehicles and especially the lesions on the victims.

The hypothesis suggested and applied to the area of analysis of macro-texture of pavements proved to be efficient, portraying the reality of the conditions of the asphalt pavement at the moment of the accident; in addition, it is juridically relevant, since it lies within the effective area of the accident.

The hypothesis suggested and applied to the moment of execution of the essays on the macro-texture of the pavement also demonstrated to be efficient. The conditions of the asphalt pavement within 24 hours after the accident, did not show any perceptible alterations which might alter the results obtained.

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