PAVEMENT ROLE IN MANAGING RISKS PRESENTED BY TRANSPORTATION OF HAZARDOUS MATERIALS

F. G. Praticò, R. Ammendola, A. Moro
D.I.M.E.T. Department-Mediterranean University of Reggio Calabria, ITALY,
filippo.pratico@unirc.it,
rachele.ammendola@unirc.it, antonino.moro@unirc.it

ABSTRACT

Nowadays, a great amount of Hazardous Materials (Hazmat) are carried “on the road” and this fact can be very important for the continuance of strong and effective national and international economies.
On the other hand, this may cause risks for people health, for safety and for property. Well-defined hazmat response policies, procedures and risk management can allow to accurately identify the hazardous material, direct further response and minimize risks. In all these processes road pavement can play a crucial role, but many aspects still need answers on this topic. In the light of above mentioned, the two main objectives of this work have been the design, construction and validation of a device to test Hot Mix Asphalt chemical resistance and the assessment of relationships in order to estimate how much a transported fluid can be dangerous depending on mix characteristics (effective porosity, etc.).This work can be useful in deciding the suitable typology of Hot Mix Asphalt to use in areas when conditions of high vulnerability or/and high probability do occur.

1. RISK ISSUES AND PERCOLATION MODELING

Hazmat spillage and propagation can cause damages to the chain driver-vehicle-road-environment, and this can be related to many classes of risks (see figure 1 [1; 2 ; 3; 4]).
Hazardous material transport is a multi-objective and multi-stakeholders problem; hazmat-related incidents (and accidents) are low-probability and high-consequence events and criteria for route selection include [5; 6]: a) minimum travel time; b) lowest accident rate; c) lowest exposed population (on road and off road population); d) traffic issues; e) infrastructure/pavement issues.
Concerning pavement issues related to risk mitigation, surface friction, bearing properties, and therefore operational speeds and traffic can be greatly affected in the short, middle and long term. Importantly, this finally influences the life-line role.
In particular, when a given mass of fuel is poured into a pavement, the starting mass M_0 (control sample or test specimen) decreases due to the loss of aggregates *(AG)* and asphalt binder (*B)*, though small quantities *I* of fuel still can remain entrapped in the specimen [7]:

$$M_d = M_0 - B + I - (AG) \cong M_0 - \Delta M \tag{1}$$

where M_d is the mass of the dry sample after hazmat percolation or soaking in the fuel.
From the equation (1) it is possible to derive the following expression (see tab. 1):

$$\frac{A_i}{100} = \left(\frac{4n_{eff}}{\phi^*} + \frac{2\alpha}{r} + \frac{1}{h} \right) \frac{\Delta t}{a} \cdot \frac{\gamma_L}{\gamma_{cb}} \tag{2}$$

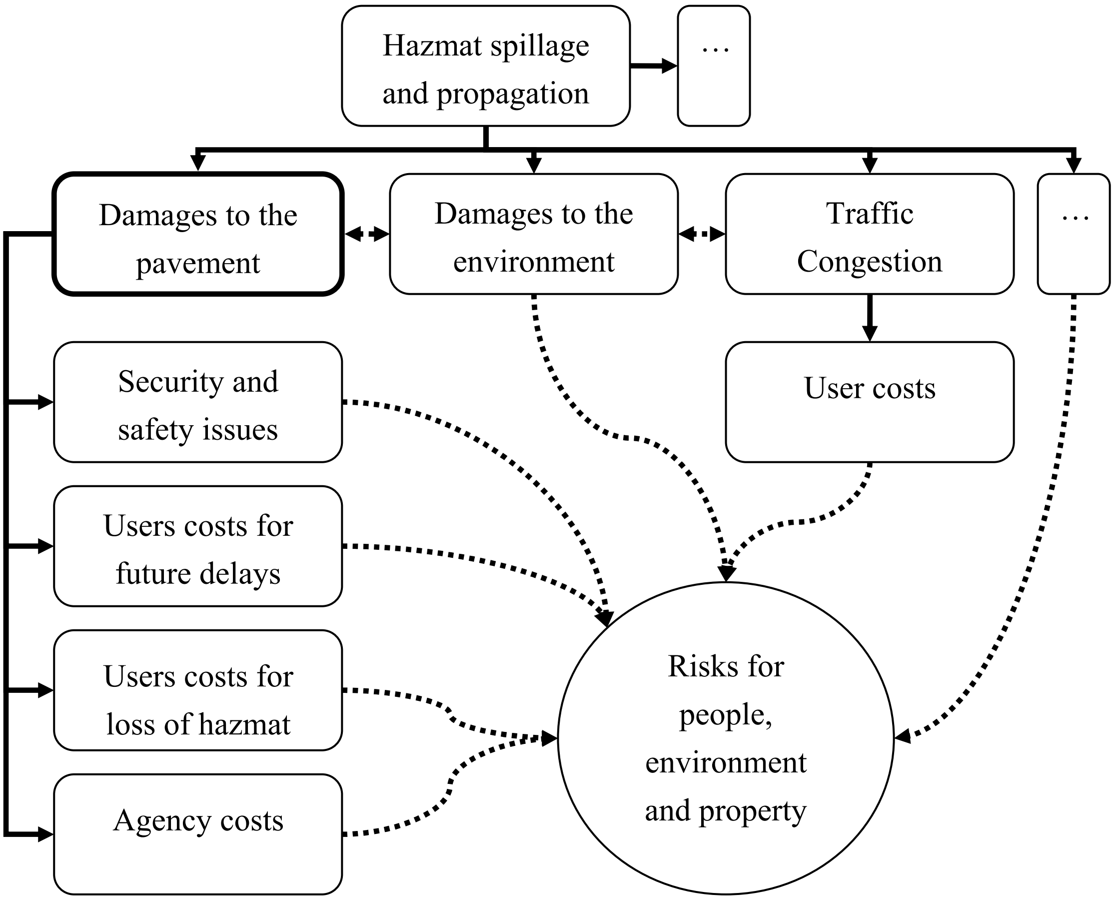


Figure 1 - Main classes of risks related to hazmat spillage on the road

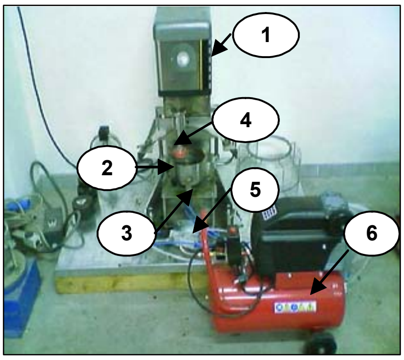
Table 1 - Symbols of the model

A_i: Mass loss after soaking in fuel $A_i=((m_{1,i}- m_{2,i})/m_{1,i})\cdot 100$; $m_{1,i}$ = initial dry mass of the specimen *i* the for soaking in fuel, (g); $m_{2,i}$ = mass of the dry test specimen *i* after soaking in fuel, (g). $A=\Sigma_i A_i/3$.
n_{eff}: Effective porosity.
ϕ^*: Reference diameter of the pores.
α: Adimensional parameter ($0 \le \alpha \le 1$), $\alpha \cong h_l/h \cong 0{,}55$.
h_l, h: Height of the fuel around the sample and sample height.
r: Radius of the sample.
Δt: Immersion time; $\Delta t = 72^h \pm 30$ min (polymer-modified bitumen) or $\Delta t = 24^h \pm 30$ min.
a: Parameter which takes into account asphalt binder, size and shape of the flow paths, fuel characteristics, etc; it has the dimensions of the reciprocal of a speed.
$\gamma_L;\gamma_{cb}$: Specific gravity of the loss mass; specific gravity of the specimen.

In order to pursue the above-mentioned objects, following the model set out in this section, a device has been designed and constructed and experiments have been planned and performed.

2. CONSTRUCTION OF THE DEVICE

A device to estimate the resistance of HMAs (Hot Mix Asphalts) to Hazmat spillage and traffic subsequent action has been designed, constructed and calibrated at the DIMET Department of the University of Reggio Calabria – Italy, in order to estimate *A*, *B* and *C* (EN 12697-43:2005, see figure 2), where: *A(%)*, mean value of the loss of mass after soaking in fuel (Diesel oil), has been defined (together with $m_{1,i}$ and $m_{2,i}$) in table 1; $B(\%)$ = mean value of the loss of mass after the brush test, where $B=\Sigma_i B_i/3$, with $i=1, 2, 3$ (n° specimen), $B_i=((m_{2,i} - m_{5,i})/ m_{2,i})\cdot 100$, $m_{5,i}$= mass of the test specimen i after soaking and 120 s in the brush test, in grams (g); $C(\%)$ =mean value of the loss of mass of the specimens, where $C=\Sigma_i C_i/3$, with $i=1, 2, 3$ (n° specimen), $C_i=((m_{1,i}- m_{5,i})/ m_{1,i})\cdot 100$. Note that C has been introduced in order to have a descriptor able to combine the two different actions (soaking + brushing) and probably better representative of post-spillage pavement performance.



ID	Component
1	Mixer B205/20 (60±2 rpm, 20 l).
2	Steel ring (di=152±2 mm, thickness ≅ 2mm).
3	Pneumatic actuator (DSNU–20-72-P-A).
4	Steel brush (do=60mm, di=30mm, 8500 rpm).
5	Manometer (MS4-LFR-1/4- D7-CRM-AS).
6	Compressor (24l, HP2)

Figure 2 - Brush tester (EN 12697-43:2005).

3. EXPERIMENTS

In order to estimate how much a given fuel can be dangerous for a given HMA, five different classes of bituminous mixes have been tested: DGFC (Dense Graded Friction Course), BIC (BInder Course), BAC (BAse Course), PEM (Porous European Mixes) and SMA (Splitt Mastix Asphalt). Table 2 summarizes the mean composition of the selected mixes (aggregate grading, asphalt binder content, effective porosity).

Table 2 - Main composition parameters of the five mixes

	Percent Passing (%)				
ϕ (mm) Sieve Size	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**
40	100.00	100.00	100.00	100.00	100.00
30	100.00	100.00	87.10	100.00	100.00
25	100.00	92.20	64.30	100.00	100.00
15	100.00	69.90	50.40	85.52	99.05
10	99.29	50.20	42.30	39.52	92.75
5	66.45	40.00	35.60	21.71	44.44
2	36.45	27.20	27.80	15.41	26.83
0.4	13.83	13.70	15.40	9.18	14.11
0.18	12.48	7.00	8.50	7.30	9.60
0.075	7.66	4.00	4.30	5.03	7.69
b %	5.3-5.7	4.8	4.5	4.4-5.2	6.10
n_{eff} (%)	6.5-17.1	5.9-6.0	6.9-8.0	13.5-29.5	9.5-11.3
Symbols Mix 1 = Dense-graded friction course, Mix 2 = Binder course, Mix 3 = Base course, Mix 4 = Porous European Mix, Mix 5=SMA					

The following sections summarize the main experiments performed in order to pursue the above-mentioned objectives.

3.1. Volumetric tests

The following parameters have been determined: *b (%)* = asphalt binder content as a percentage of aggregate weight (B.U. CNR n.38/73; ASTM 6307); *G* = aggregate gradation (B.U. CNR n. 4/53); NMAS = Nominal Maximum Aggregate Size; *f (%)* = filler content ($d \leq 0.075$ mm); *s(%)* = sand content ($0.075 \text{ mm} \leq d \leq 2$ mm); γ_g = aggregate apparent specific gravity (B.U. CNR n. 63/78); G_{mb} = mix bulk specific gravity (ASTM D6752; ASTM D6857) (see Figure 3); G_{mbAO} = mix bulk specific gravity after opening (ASTM D6752; ASTM D6857); n_{eff} = mix effective porosity (ASTM D6752; ASTM D6857) (see Figure 3). The effective porosity (n_{eff}) has been calculated from G_{mb} and G_{mbAO}: $n_{eff}=(G_{mbAO}\cdot\gamma_w - G_{mb}\cdot\gamma_w)\cdot(G_{mbAO}\cdot\gamma_w)^{-1}$, γ_W = water density.

3.2. Permeability tests

K_{cv}, the coefficient of water permeability, has been calculated, using a Flexible Wall Permeameter – FWP (ASTM PS 129-01) (see Figure 4), according to the formula: $K_{cv}=R_T \cdot a_{cs}\cdot l\cdot A_{cs}^{-1}\cdot t^{-1}\cdot ln\,(h_1/h_2)$, where a_{cs} is the inside cross-sectional area of inlet standpipe (cm^2); l is the thickness of test specimen (cm); A_{cs} is the cross-sectional area of test specimen (cm^2); t is the average elapsed time of water flow between timing marks (s); h_1 is the initial hydraulic head on specimen (cm); h_2 is the final hydraulic head on specimen (cm); R_T is a coefficient that corrects the calculated K at given temperature to that for 20°C.

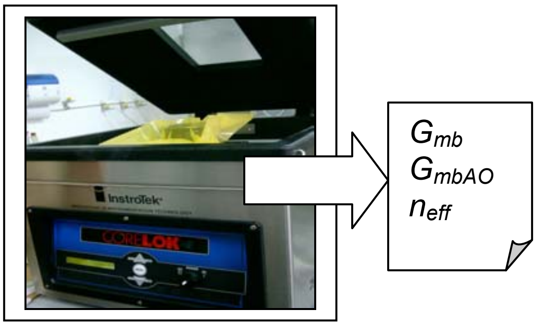


Figure 3 - Vacuum Sealing Device

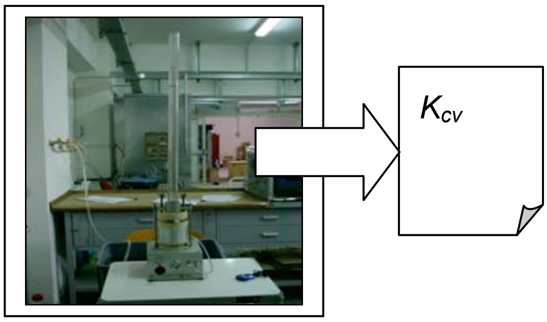


Figure 4 - Flexible Wall Permeameter

4. RESULTS

Figures 5 to 19 summarize the obtained results. Figures 5 to 7 refer to the dependence of chemical resistance (A, B, C) on n_{eff} (effective porosity of pavement) for all the mixes.
Results show a strong dependence on n_{eff} of the mass loss after soaking (A), of the mass loss after brush test (B) and of the mass loss for combined action (Soaking + Brushing, C). R-square values range from 0.64 up to 0.83 and result increased respect previous experiments [7]. In figures 8 to 10, results are organized according to mix typology, while figures 11 to 13 refer to PEMs (Porous European Mixes) chemical resistance when n_{eff} increases.

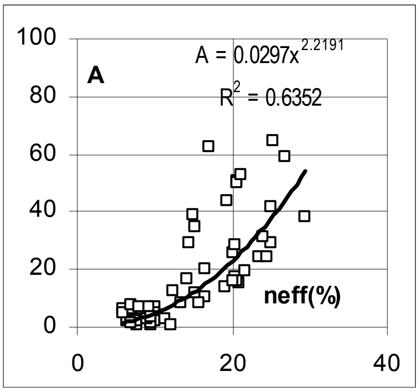


Figure 5 - A vs neff(%).

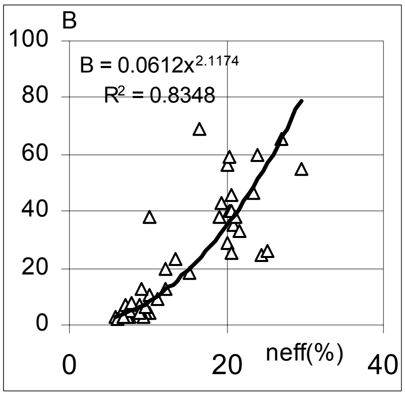


Figure 6 - B vs neff(%).

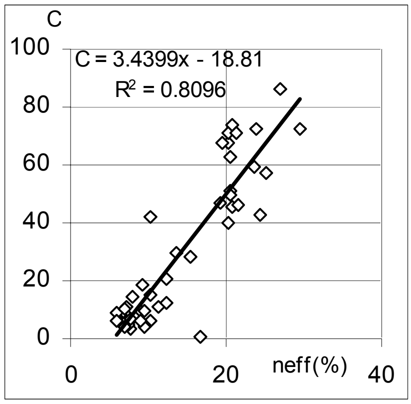


Figure 7 - C vs neff(%).

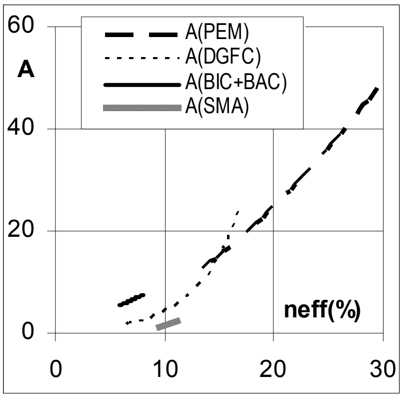


Figure 8 - A vs. neff(%).

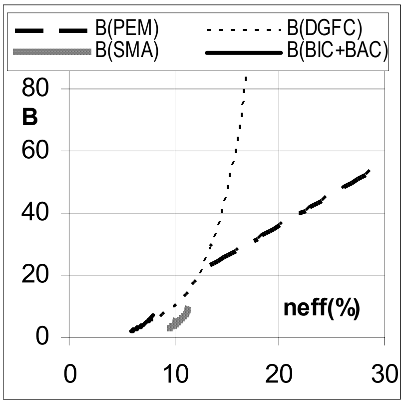


Figure 9 - B vs. neff(%).

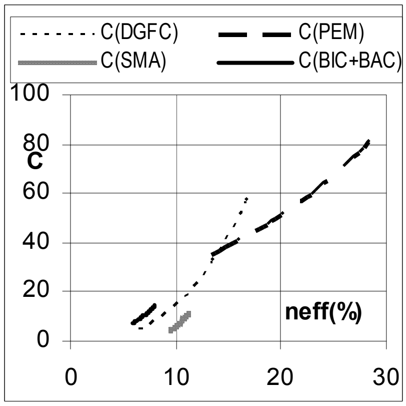


Figure 10 - C vs. neff(%).

Table 3 summarizes the obtained results. First derivatives appear variable: the steepest positive slope are related to dense – graded mixes. It is important to remark that PEMs variance does not appear sufficiently explained by changes in effective porosity (see figures 11 to 13, in which R-square values are reported).

Table 3 - Regression curves

Mix type	A	B	C
PEM	$A = 0.1445 \cdot n_{eff}^{1.7156}$; $R^2 = 0.341$	$B = 1.3088 \cdot n_{eff}^{1.1044}$; $R^2 = 0.2872$	$C = 16.703 \cdot \exp(0.0555 \cdot n_{eff})$; $R^2 = 0.4248$
DGFC	$A = 0.3034 \cdot \exp(0.2599 \cdot n_{eff})$; $R^2 = 0.5592$	$B = 0.4246 \cdot \exp(0.3117 \cdot n_{eff})$; $R^2 = 0.7436$	$C = 0.0293 \cdot n_{eff}^{2.6859}$; $R^2 = 0.6671$
BIC+ BAC	$A = 0.8693 \cdot n_{eff}^{1.0346}$; $R^2 = 0.4759$	$B = 0.0595 \cdot \exp(0.5991 \cdot n_{eff})$; $R^2 = 0.8518$	$C = 1.0852 \cdot \exp(0.3233 \cdot n_{eff})$; $R^2 = 0.8396$
SMA	$A = 0.9053 \cdot n_{eff} - 7.4752$; $R^2 = 0.7399$	$B = 0.0156 \cdot \exp(0.5618 \cdot n_{eff})$; $R^2 = 0.8723$	$C = 10^{-05} \cdot n_{eff}^{5.6687}$; $R^2 = 0.9592$

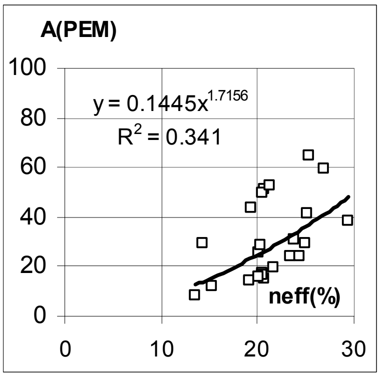


Figure 11 - A vs. neff(%)

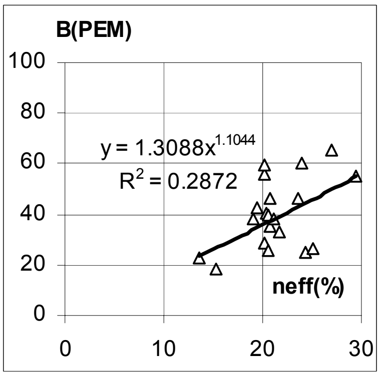


Figure 12 - B vs. neff(%)

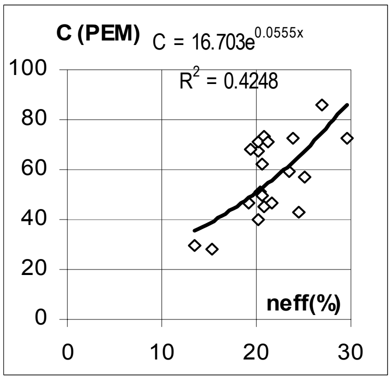


Figure 13 - C vs. neff(%)

Figures 14 to 16 show hydraulic conductivity influence on chemical resistance while figures 17 to 19 summarize the correlations among the selected "effects" (i.e. A, B, C). The sensitivity of the three indicators *A*, *B*, *C* to the hydraulic conductivity K_{cv} (FWP device, PEMs) appears to be quite optimized if compared to previous experiments [7]. In some measure, this fact could be due to the "stretching" of the curves on the x-axis, here caused by the consideration of both dense-and open-graded mixes.

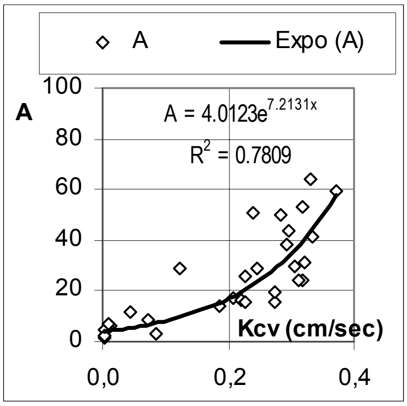


Figure 14 - A vs K_{cv}.

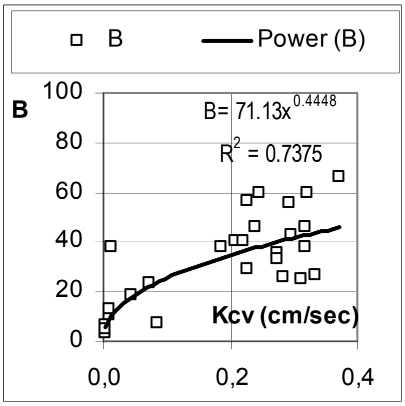


Figure 15 - B vs K_{cv}.

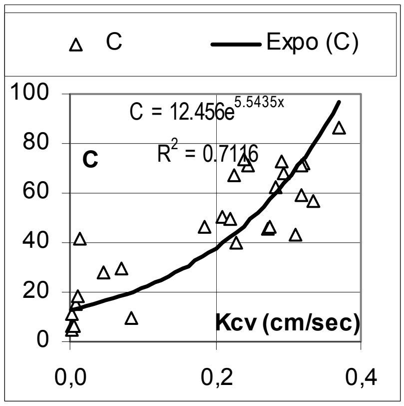


Figure 16 - C vs K_{cv}.

Concerning the correlations among the three selected indicators (figures 17 to 19), Brushing and Soaking susceptibility seem quite well-correlated (R^2_{AB}=0.68); of course, the combined susceptibility (C: Brushing + Soaking) appears to be better related both to the behaviour in soaking process (R^2_{AC}=0.75) and to the descriptor of Brushing process (R^2_{BC}=0.72).

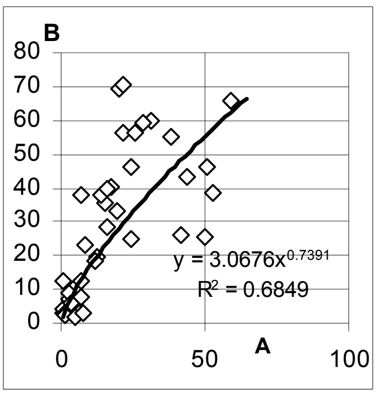


Figure 17 - A vs B

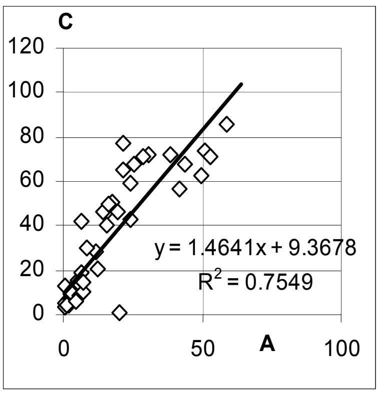


Figure 18 - A vs C

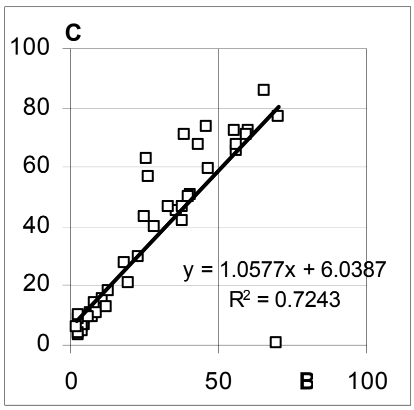


Figure 19 - B vs C

5. MAIN FINDINGS

The following main findings may be drawn: i) international literature and many case histories support the strategic role of pavement and infrastructure in managing hazmat transportations on the road; ii) theoretical (equation 2) and experimental outputs prove the dependence of chemical resistance of the pavement on effective porosity and hydraulic conductivity; therefore, n_{eff} and K_{cv} significance and role in explaining and controlling HMA durability is confirmed not only for fatigue issues but also in terms of chemical resistance; iii) DGFCs seem to have a singular behavior in terms of chemical resistance dependence on n_{eff} (great variation of the first derivative); iv) on the basis of the obtained results, compared with previous experiments [7], it is possible to suppose a relative stability and robustness of the coefficients obtained for the fitting curves (n_{eff} – A – B – C correlations), for the given asphalt binder and fuel; v) it is confirmed that the variable C could have two important characteristics: representativeness and predictability; in fact, is seems to be enough representative of the actual damage on the road and it is well-correlated to both intrinsic (porosity) and extrinsic (permeability) properties; vi) R-square values appear to be optimized if compared to previous works [7]: this is probably due to the increased amount of data and to the larger ranges of variations.

REFERENCES

1. Minseok Kim (2006). A heuristic for routing hazmat transport given real-time weather and traffic information, Thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park - degree of Master of Science 2006.
2. Giordani Stefano (2005). Modelli e metodi per la definizione di piani per il trasporto di merci pericolose, PRIN - Programmi di Ricerca di Rilevante Interesse Nazionale, Università degli Studi di Roma "Tor Vergata".
3. Nicolet-Monnier, M. and Gheorge, A. V. (1996). Quantitative Risk Assessment of Hazardous Materials Transport Systems: Rail, Road, Pipelines & Ship. Kluwer Academic Publishers.
4. AA.VV. (2002). A Study of Hazards and Risks to Public Health and Safety, the Environment, and the Economy Associated with the Transportation of Hazardous Materials, As Required Under Section 352(b) of the Department of Transportation and Related Agencies Appropriations Act, U.S. Department of Transportation, Research and Special Programs Administration, Office of Hazardous Materials Safety, Washington, D.C. 20590, FINAL REPORT, June 18.
5. Masoud Hamedi, Saini Yang, Ali Haghani (2006). Routing and Scheduling of Hazmat Fleet to Avoid Risk Accumulation, University of Maryland at College Park January, 25.
6. Parsons Brinckerhoff Quade & Douglas (2006). Risk Analysis Study of Hazardous Materials Trucks through Eisenhower / Johnson Memorial Tunnels, FINAL REPORT, Colorado Department of Transportation, June.
7. Praticò F.G., Ammendola R. and Moro A. (2007). Influence of mix parameters on fuel resistance of porous and dense - graded HMAs. International Conference: Advanced Characterisation of Pavement and Soil Engineering Materials, Athens, Greece, June.