Progetto cofinanziato dall'Unione Europea nell'ambito del programma LIFE+
LIFE10ENV/IT/000390

TYREC4LIFE: Innovative technologies and environmental solutions for road pavements

Research contribution of the Politecnico di Torino

prof. Ezio Santagata

Turin, September 18, 2015

TORINO METROPOLI Città metropolitana di Torino
PATRIMONIO Città di Settimo Torinese s.r.l.
CRF
Impresa BRILLADA VITTORIO&c
CENTRO ESTERO INTERNAZIONALIZZAZIONE PIEMONTE Agency for Investments, Export and Tourism

RESEARCH APPROACH

Multidisciplinary studies:

PAVEMENT ENGINEERING + ENVIRONMENTAL SANITARY ENGINEERING

(prof. E. Santagata) (prof. M.C. Zanetti)

Actions of contribution:

EVALUATION

EXPERIMENTAL INVESTIGATION AND TECHNOLOGICAL DEVELOPMENT

IMPLEMENTATION AND VALIDATION

LIFE-CYCLE RISK ASSESSMENT

DISSEMINATION

2. Evaluation actions

2.4: Availability and characterization of natural and recycled aggregates

2.5: Availability and characterization of CR from ELTs

2.4: Availability and characterization of natural and recycled aggregates

1) **Standard aggregates**
    - Analysis of Regional Quarry Plan database;
    - Analysis of LMS-PoliTO database.

2) **Innovative aggregates**
    - From the incineration plant of the City of Turin;
    - RAP (Reclaimed Asphalt Pavement)

3) **Detailed analysis of candidate aggregates for G-G bituminous mixtures**
    - Complete characterization;
    - Preparation of G-G mixtures with 8% binder (18% CR);
    - Volumetric and mechanical characterization.

2.4: Availability and characterization of natural and recycled aggregates

1) Standard aggregates - Analysis of the Regional Quarry Plan (example)

Area and/or Basin	L.A.
Bormida-Scrivia	20,0
Dora Baltea-Po	30,0
Cervo-Dora B.	25,8
Maira-Pellice	23,8
Pesio-Stura D.	31,5
Po	29,4
Tanaro	29,7
Ticino-Sesia	23,8
Sesia-Dora Baltea	25,5
F.G. Dora B.-Po	32,5
F.G. Sesia -Dora B.	27,6
F.G. Sesia -Ticino	31,6
F.G. Stura D.-Po	24,0

Source	quartz	feldsp.	miche	femic	carb.	other
Bormida-Scrivia	20	5	5	35	0	35
Cervo-Elvo-Dora B.	25	7,5	2,5	25	5	35
Dora B.-Po	40	10	5	25	5	5
Maira-Pellice-Varaita	22,5	15	5	35	10	12,5
Pesio-Stura D.	30	10	5	25	15	20
Po	35	10	5	25	10	15
Sesia-Cervo	30	10	10	35	10	5
Tanaro	27,5	0	5	30	7,5	30
Ticino-Sesia	55	10	7,5	13	0	15
F.G. Dora B.-Po	27,5	13	10	20	7,5	22,5
F.G. Sesia -Dora B.	20	5	5	38	10	22,5
F.G. Sesia -Ticino	45	7,5	5	13	2,5	27,5

2.4: Availability and characterization of natural and recycled aggregates

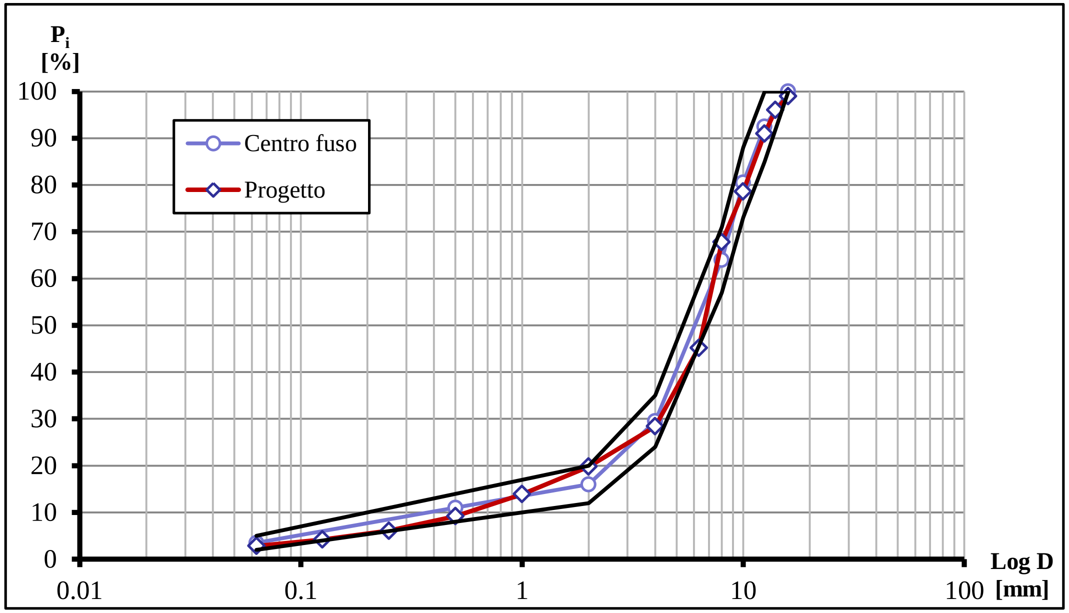
2) Innovative aggregates – Municipal Solid Waste Bottom Ashes

Componente	***% in peso***
Legno e tessuti	*6*
Carta e cartone	*22*
Materie plastiche e gomma	*15*
Vetro	*5*
Ceramici	*7*
Metallo	*5*
Sostanze organiche	*31*
Sottovaglio	*9*

2.4: Availability and characterization of natural and recycled aggregates

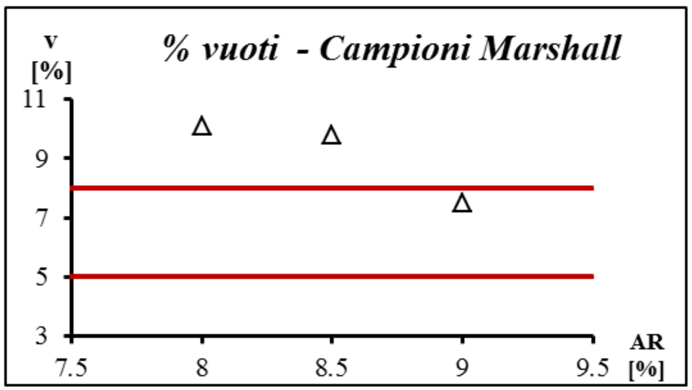
2) Innovative aggregates – Municipal Solid Waste Bottom Ashes

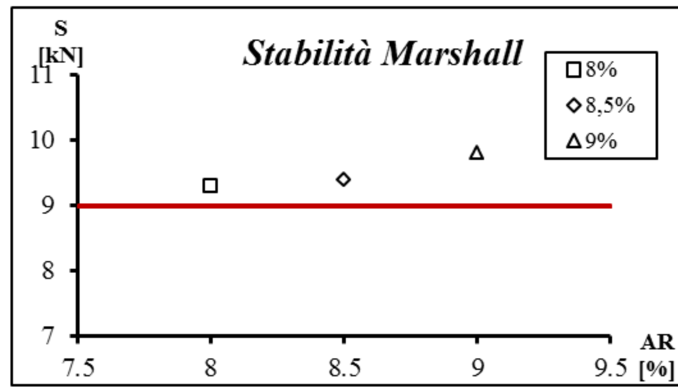
MISCELA GAP GRADED ARI	
Classi di Aggregato	***Quantitativo [%]***
Ceneri pesanti	*21*
8-12	*25*
4-8	*37*
0-4	*17*

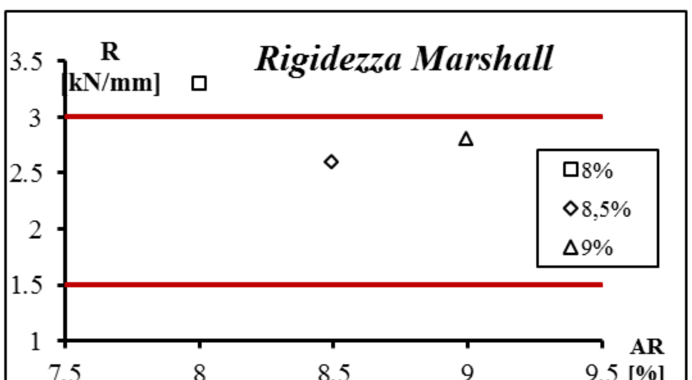


2.4: Availability and characterization of natural and recycled aggregates

2) Innovative aggregates – Municipal Solid Waste Bottom Ashes



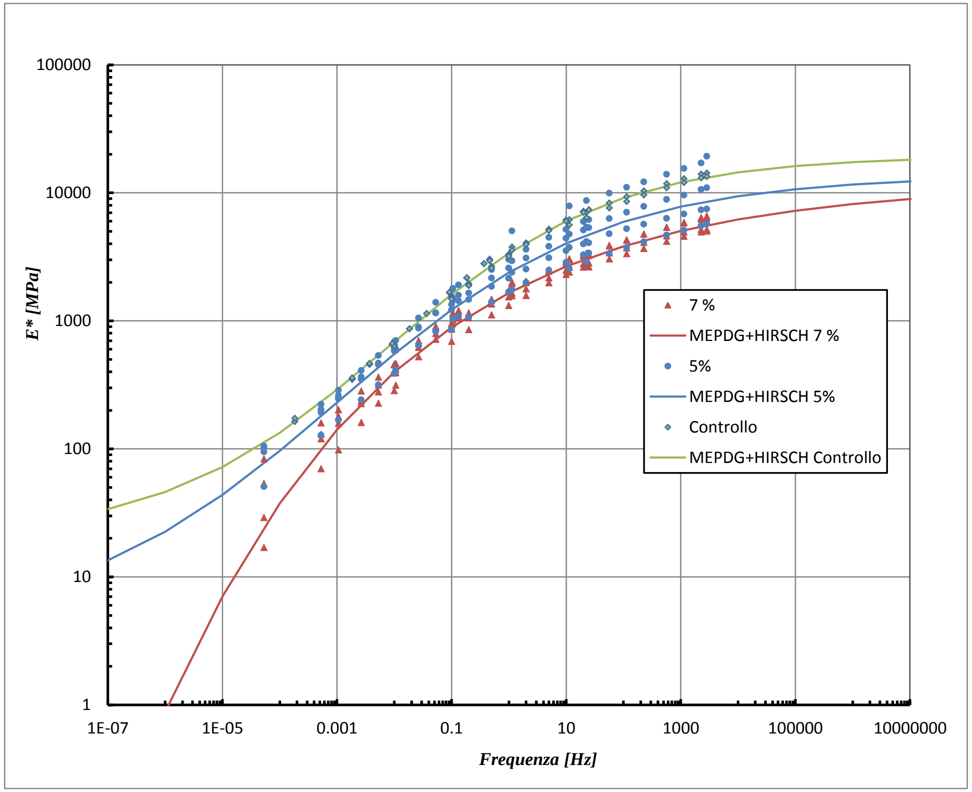




Miscela AR [%]	*v* [%]	*S* [kN]	*R* [kN/mm]
8%	*10,1*	*9,3*	*3,3*
8,5%	*9,8*	*9,4*	*2,6*
9%	*7,5*	*9,8*	*2,8*

2.4: Availability and characterization of natural and recycled aggregates

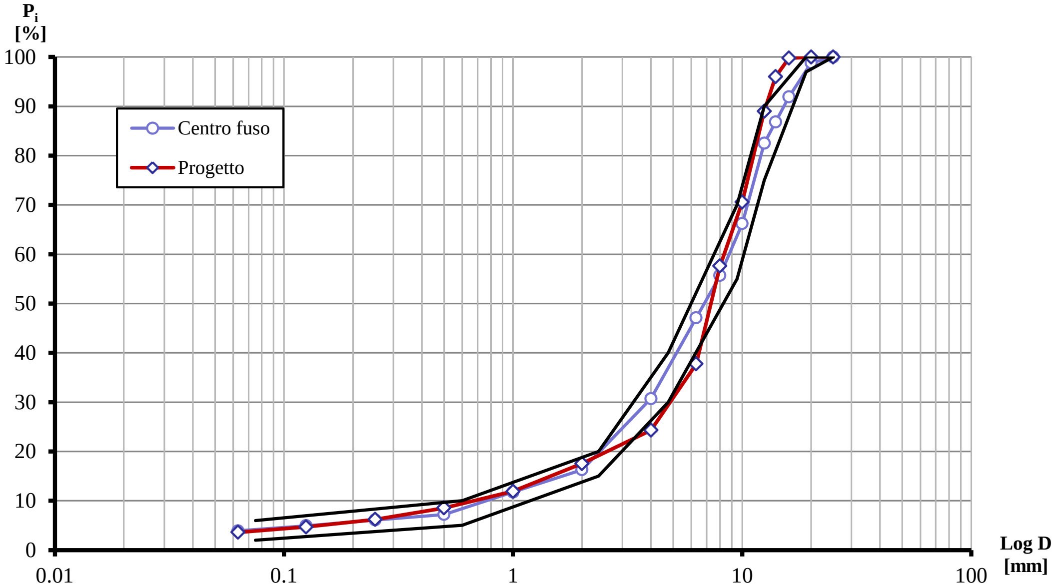
2) Innovative aggregates – Municipal Solid Waste Bottom Ashes



2.4: Availability and characterization of natural and recycled aggregates

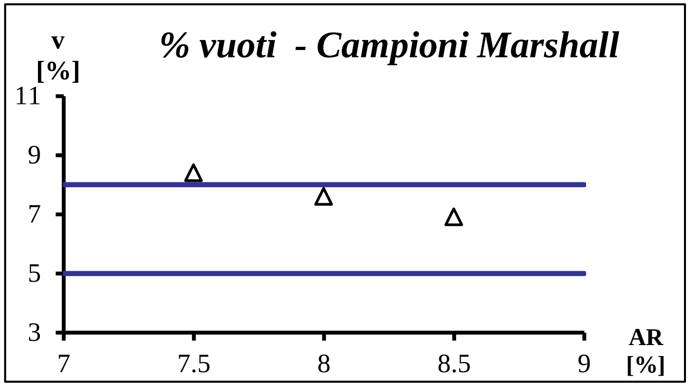
2) Innovative aggregates – RAP

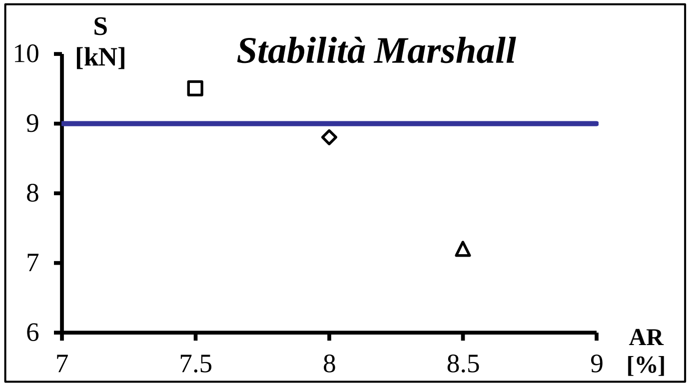
MISCELA GAP GRADED ARI	
Classi di Aggregato	***Quantitativo [%]***
RAP	*10*
8-12	*42*
4-8	*31*
0-4	*17*

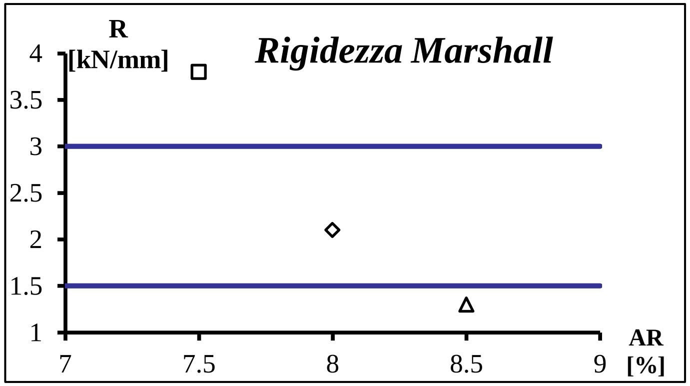


2.4: Availability and characterization of natural and recycled aggregates

2) Innovative aggregates – RAP





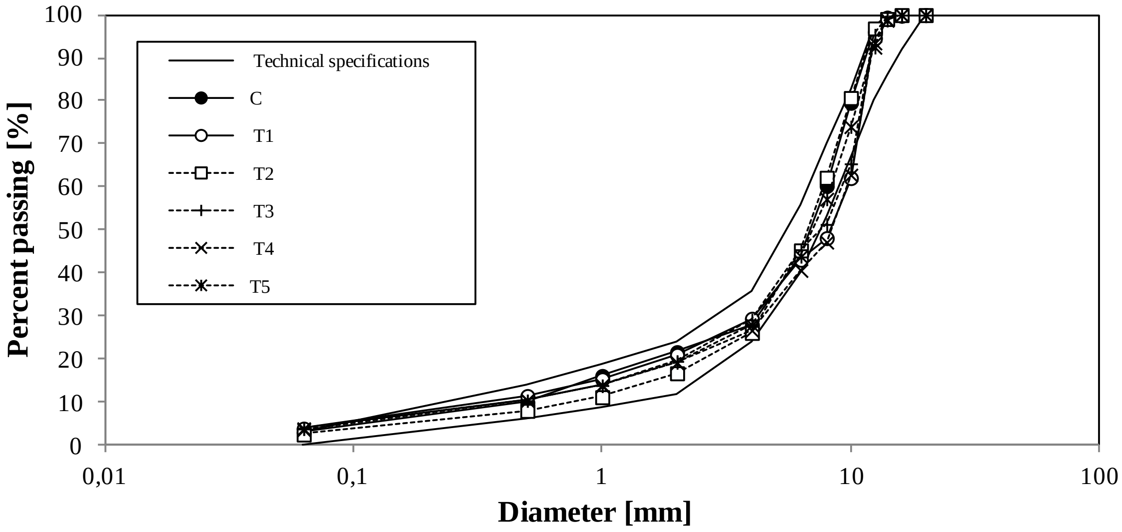


Miscela AR [%]	v [%]	S [kN]	R [kN/mm]
7.5	8.4	9.5	3.8
8	7.6	8.8	2.1
8.5	6.9	7.2	1.3
7.8	7.9	9.0	2.9

2.4: Availability and characterization of natural and recycled aggregates

3) Detailed analysis of candidate aggregates for G-G bituminous mixtures

	C	T
Fraction 0/5	26%	30%
Fraction 5/10	25%	16%
Fraction 10/15	49%	54%
Asphalt rubber	8.0%	8.0%



2.4: Availability and characterization of natural and recycled aggregates

3) Detailed analysis of candidate aggregates for G-G bituminous mixtures

	"C" aggregates								"T" aggregates		
	Marshall specimens (M)				Gyratory specimens (G)				M	M	G
%B [%]	7.3	8.3	8.6	9.5	7.3	8.3	8.6	9.5	9.0	8.3	8.3
ρ [g/cm^3]	2.311	2.329	2.331	2.355	2.327	2.369	2.388	2.392	2.285	2.352	2.343
TMD [g/cm^3]	2.518	2.473	2.455	2.438	2.518	2.473	2.455	2.438	2.424	2.472	2.472
%v [%]	8.3	5.8	5.1	3.4	7.6	4.2	2.8	1.9	5.8	4.8	5.2
VMA [%]	24.7	24.6	24.6	25.2	24.2	23.1	22.7	24.0	24.2	22.5	22.8
VFB [%]	66.6	76.4	79.6	86.5	68.6	82.9	88.0	92.1	76.3	78.5	77.2
S [kN]	7.5	7.4	6.8	7.7	-	-	-	-	7.2	8.5	-
f [mm]	3.7	3.3	4.3	3.5	-	-	-	-	2.7	4.1	-
ITS [N/mm^2]	-	-	-	-	0.96	0.87	1.03	0.89	-	-	1.19
SR_{15days} [%]	96.0	105.4	102.9	101.3	-	-	-	-	-	96.1	-
$ITSR_{7days}$ [%]	-	-	-	-	98.7	105.6	93.8	109.8	-	-	103.7

2.5: Availability and characterization of CR from ELTs

1) **Analysis of ELT treatment plants**
    - Evaluation of treatment techniques;
    - Sampling.

2) **Physical-chemical characterization of CRs**
    - Size distribution;
    - Density;
    - Morphology and surface area;
    - Heavy metals (Al, As, Ba, Cd, Co, total Cr, Cu, Fe, Mn, Ni, Pb, Sb,Ti, Zn);
    - PAH (polycyclic aromatic hydrocarbons);
    - VOC (volatile organic compounds);
    - Elemental analysis (C, H, N, S).

2.5: Availability and characterization of CR from ELTs

1) Analysis of ELT treatment plants

Ambient size

Cryogenic

HP waterjet

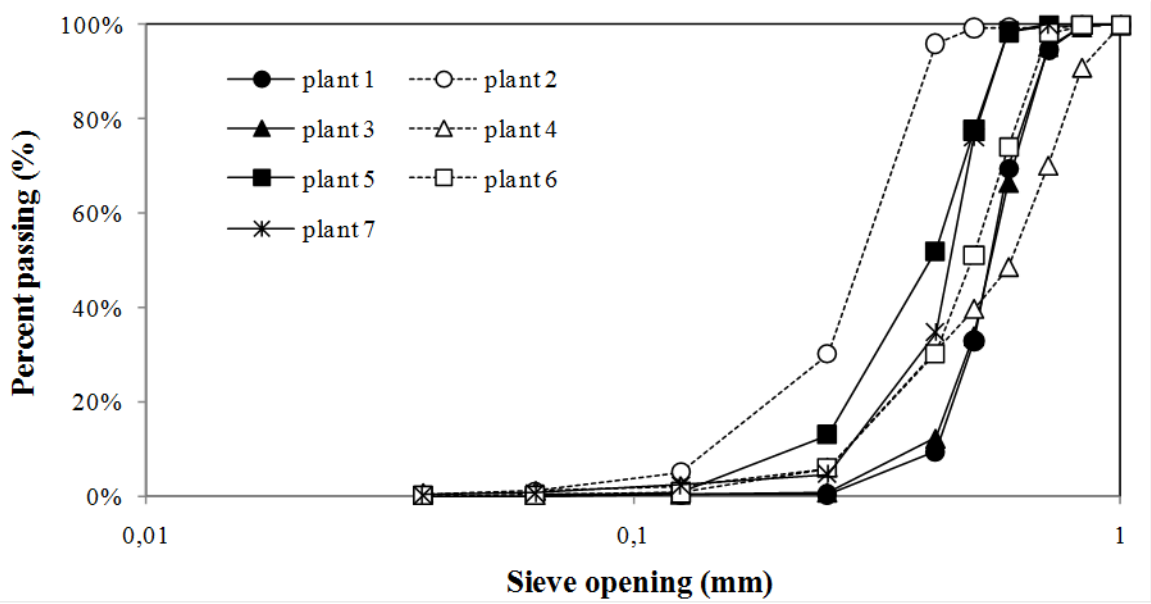
2.5: Availability and characterization of CR from ELTs

1) Analysis of ELT treatment plants

Phase	Treatment plant						
	1	2	3	4	5	6	7
Primary shredding	×	×	×	×	×*	×	×
Iron magnetic separation							×
Secondary shredding		×					×
Cold granulation		×					
Iron magnetic separation	×	×	×	×	×	×	×
Milling	×	×	×	×	×*	×	×
Sieving	×	×	×	×	×	×	×

2.5: Availability and characterization of CR from ELTs

2) Physical-chemical characterization of CRs



2.5: Availability and characterization of CR from ELTs

2) Physical-chemical characterization of CRs

Element		Treatment plant						
		1	2	3	4	5	6	7
Na	(mg/kg)	216	231	214	230	252	229	198
K	(mg/kg)	506	586	530	559	357	300	407
Ca	(%)	0.349	0.546	0.180	0.345	1.12	0.130	0.496
Mg	(mg/kg)	444	542	397	445	344	246	1240
Fe	(%)	0.153	0.245	0.169	0.215	0.147	0.042	0.223
Mn	(mg/kg)	14.7	23.9	16.1	19,6	15.8	5.07	25.3
Ba	(mg/kg)	13.2	20.3	10.9	211	121	6.29	18.7
Al	(mg/kg)	630	779	493	800	653	372	675
Cd	(mg/kg)	4.59	4.48	5.79	3.40	2.43	2.17	2.89
Cr	(mg/kg)	4.73	6.27	6.69	5.07	3.51	2.29	12.3
Ni	(mg/kg)	11.5	9.13	9.87	9.22	4.54	3.84	11.0
Pb	(mg/kg)	66.3	44.9	73.3	194	28.0	28.4	26.6
Cu	(mg/kg)	295	472	317	353	85.9	64.3	80.0
Zn	(%)	2.03	1.83	2.10	1.87	1.18	.16	1.33
Co	(mg/kg)	330	259	347	255	151	162	179
Ti	(mg/kg)	55.5	67.4	33.6	56.0	65.2	37.0	39.6
Sb	(mg/kg)	487	379	554	388	151	164	183
C	(%)	77.03	78.83	78.26	81.89	77.05	78.37	81.41
H	(%)	7.23	7.16	7.38	7.23	7.09	7.03	7.47
N	(%)	0.52	0.48	0.49	0.49	0.43	0.46	0.46
S	(%)	2.14	1.99	2.42	2.33	1.96	2.03	1.90

2.5: Availability and characterization of CR from ELTs

2) Physical-chemical characterization of CRs

Compound	Treatment plant						
	1	2	3	4	5	6	7
Benzene (mg/kg)	10.22	9.27	5.44	3.24	6.04	6.08	
Naphtalene (mg/kg)	0.74	0.56	0.49	0.53	0.92	0.88	1.03
Phenantrene (mg/kg)	3.76	2.32	1.73	2.02	5.22	3.65	2.99
Anthracene (mg/kg)	1.33	0.72	0.75	0.72	1.29	0.45	0.49
Fluorantene (mg/kg)	9.03	4.40	2.39	3.26	5.43	7.40	3.86
Pyrene (mg/kg)	14.23	14.46	8.65	12.24	16.49	21.15	12.76
Benzo[a]anthracene (mg/kg)	4.56	1.91		3.02	2.35	1.46	2.23
Crysene (mg/kg)		1.92		9.84			0.44
Benzo[a]pyrene (mg/kg)				4.28	10.60	2.44	2.34
Benzo[b]fluorantene (mg/kg)				100.12	166.69	54.81	41.41
Indeno[1,2,3-cd]pyrene(mg/kg)	2.93	1.62	0.18	1.21	1.42	0.36	0.28
Benzo[g,h,i]perylene(mg/kg)	5.88	4.33	0.56	5.89	6.28	1.91	1.07

3. Experimental investigation and technology development

3.1: Characterization of bituminous binders

3.2: Characterization of bituminous mixtures

3.3.1 & 3.3.2: Development and construction of a full-scale «dry» mixing prototype

3.4: Development of «dry» solutions for reduction of energy consumption and emissions

3.5: Reduced-scale test sections with «dry» technology

3.6: Reduced-scale test sections with «wet» technology

3.1: Characterization of bituminous binders

1) **Rheological characterization**
   - Viscosity;
   - Viscoelastic properties.

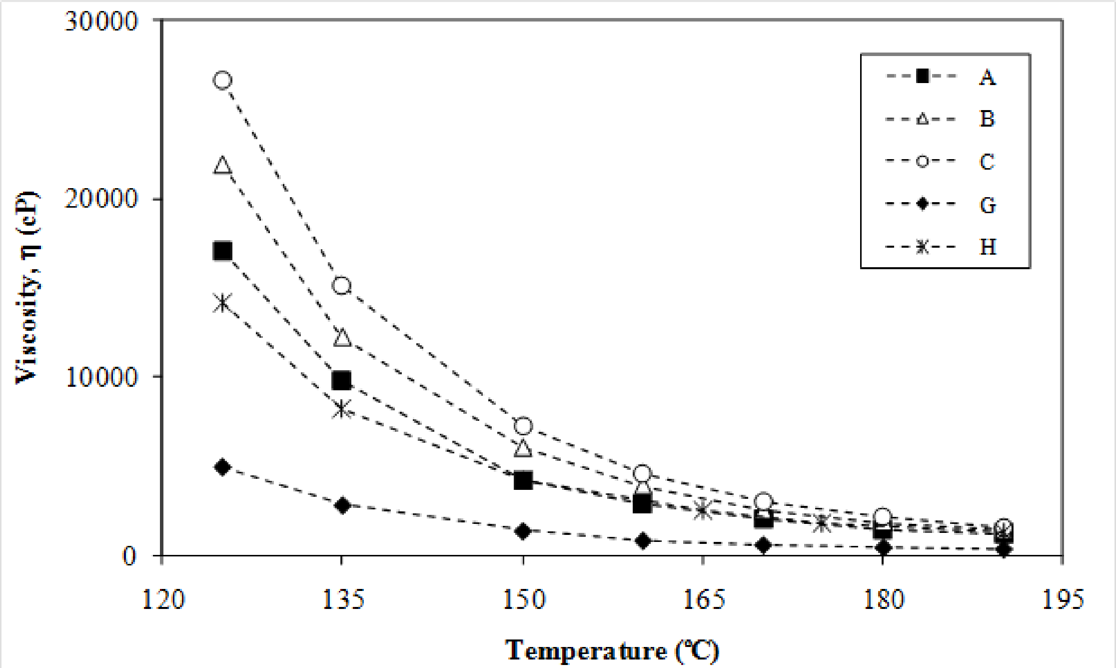
2) **Development of prediction models**
   - Viscosity/Density/Morphology.

3.1: Characterization of bituminous binders

1) Rheological characterization

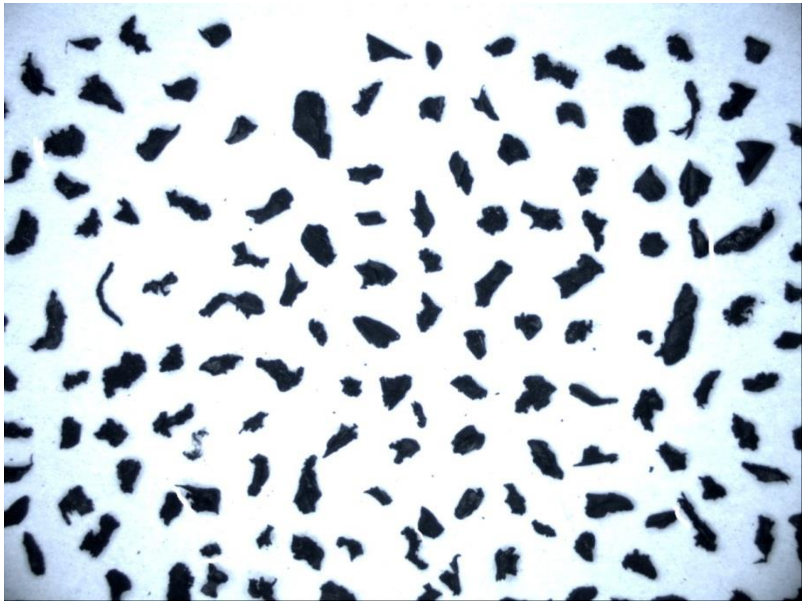
$$\eta(T) = \alpha_T \cdot T^{-\beta_T}$$

CR	A	B	C	G	H
$\%CR_w$	15.0	15.0	15.0	15.0	15.0
%CRv	15.1	15.0	15.3	14.5	14.9
α_T	6.39E+17	1.70E+18	3.91E+18	3.63E+16	1.22E+16
β_T	6.491	6.636	6.765	6.153	5.709
R^2	0.9920	0.9972	0.9981	0.9889	0.9931

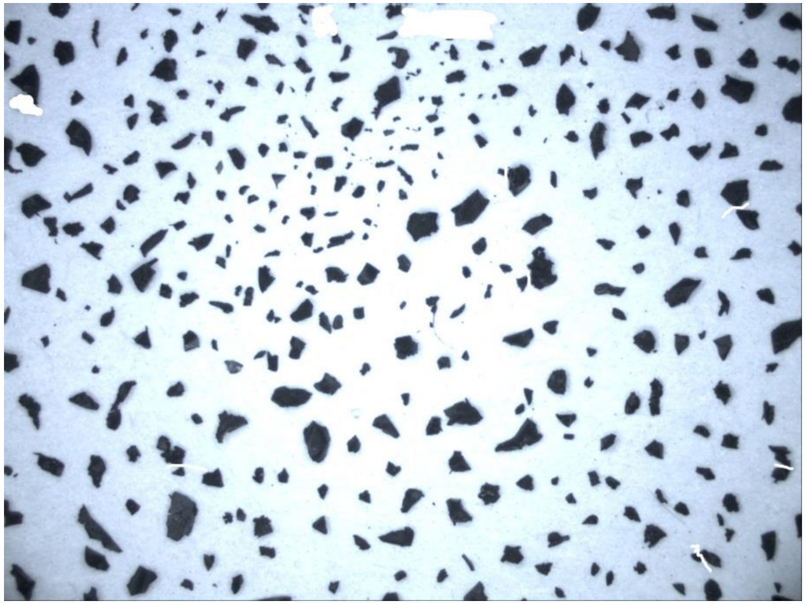


3.1: Characterization of bituminous binders

2) Development of prediction models



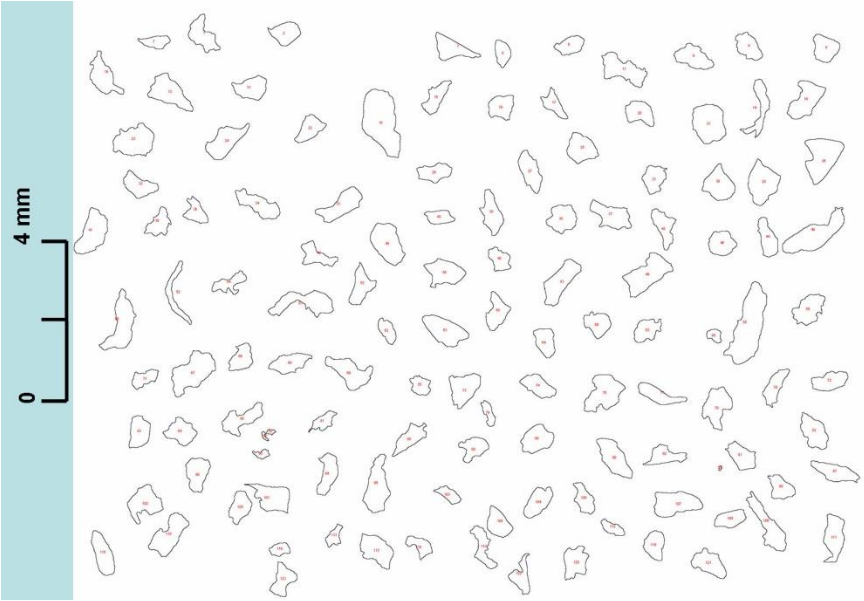
Ambient size



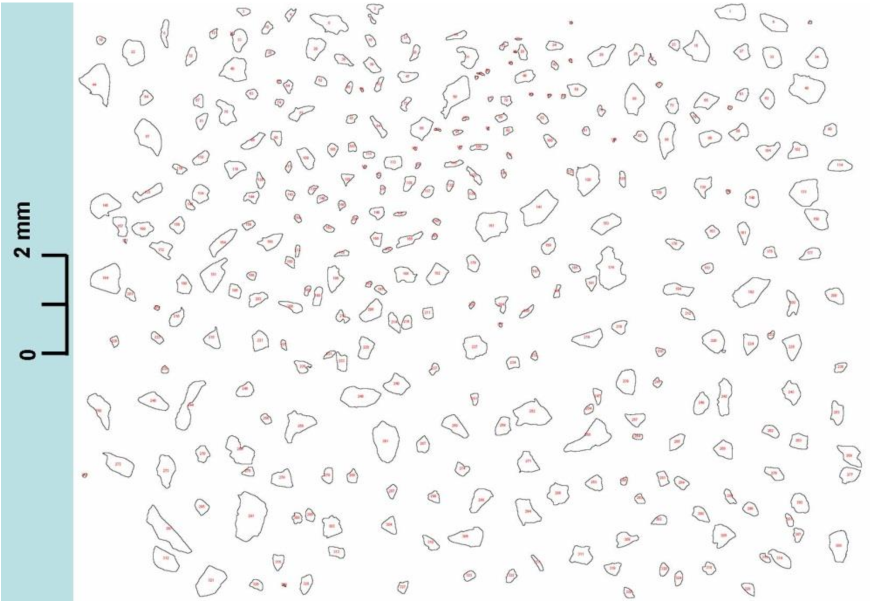
Cryogenic

3.1: Characterization of bituminous binders

2) Development of prediction models



Ambient size



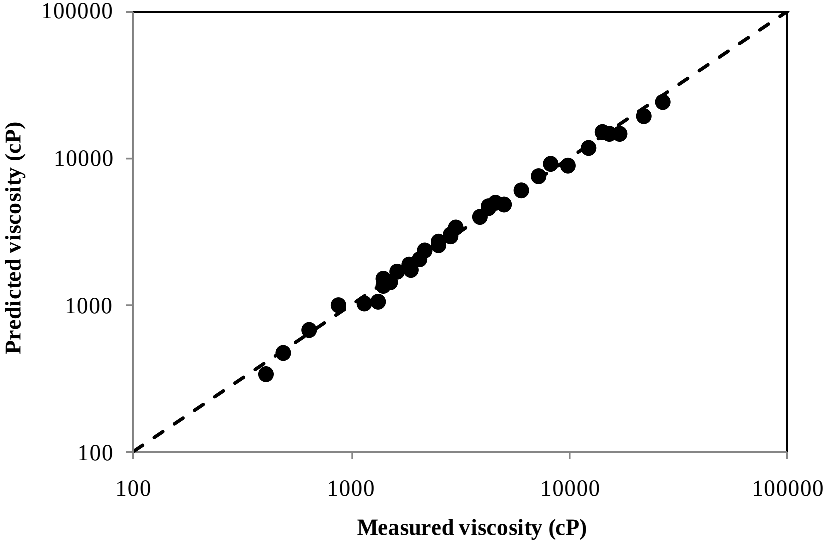
Cryogenic

3.1: Characterization of bituminous binders

2) Development of prediction models

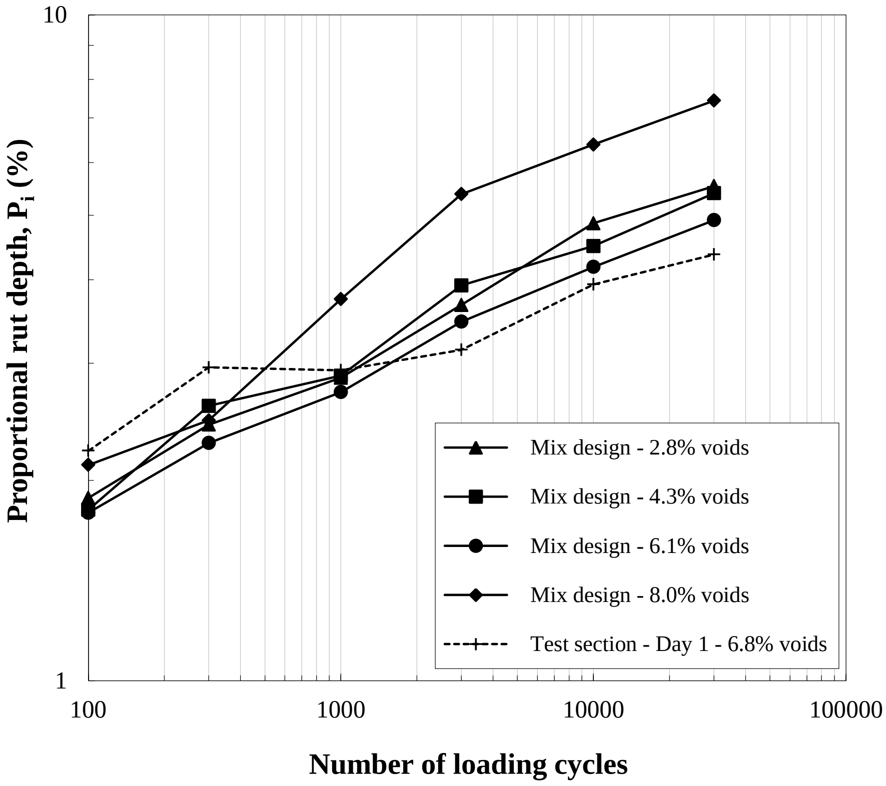
$$\eta = 10^{a_1} \cdot T^{-a_2} \cdot \rho^{-a_3} \cdot \phi^{a_4} \cdot \left(6 \cdot \sum_i \frac{f_i}{d_{m,i}}\right)^{a_5}$$

	i = 1	i = 2	i = 3	i = 4	i = 5
Model parameter a_i	15.65	6.36	12.62	0.443	8.93
Standard error se_i	0.45	0.12	2.18	0.05	0.94



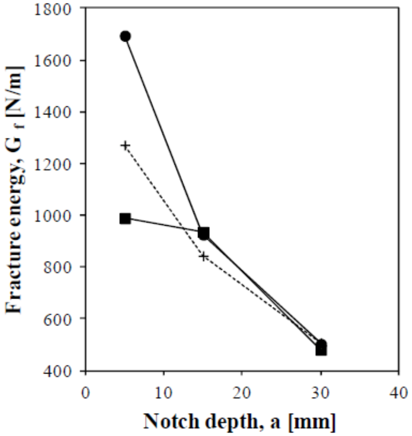
3.2: Characterization of bituminous mixtures

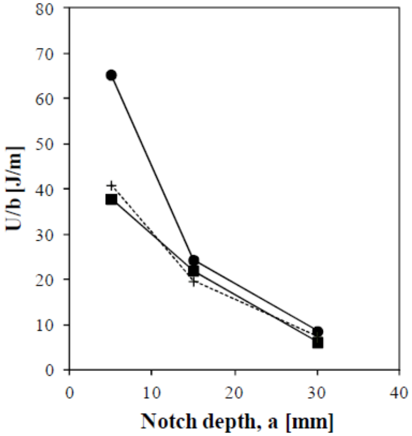
Wheel-tracking tests – RESISTANCE TO RUTTING

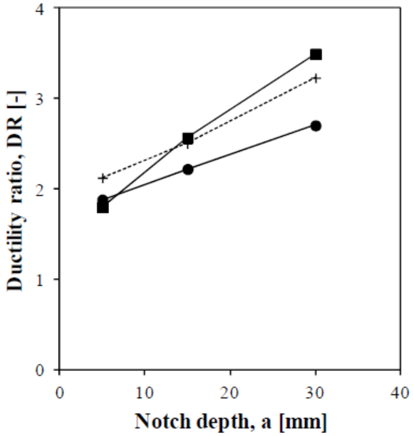


3.2: Characterization of bituminous mixtures

SCB tests – RESISTANCE TO CRACK PROPAGATION







3.2: Characterization of bituminous mixtures

MIXTURE TYPES

- Standard gap-graded mixtures (BV, ZA);
- Low binder content gap-graded mixtures (TB);
- Coarse gap-graded mixtures (SG);
- Fine dense-graded mixtures (CE);
- Coarse dense-graded mixtures (SD).

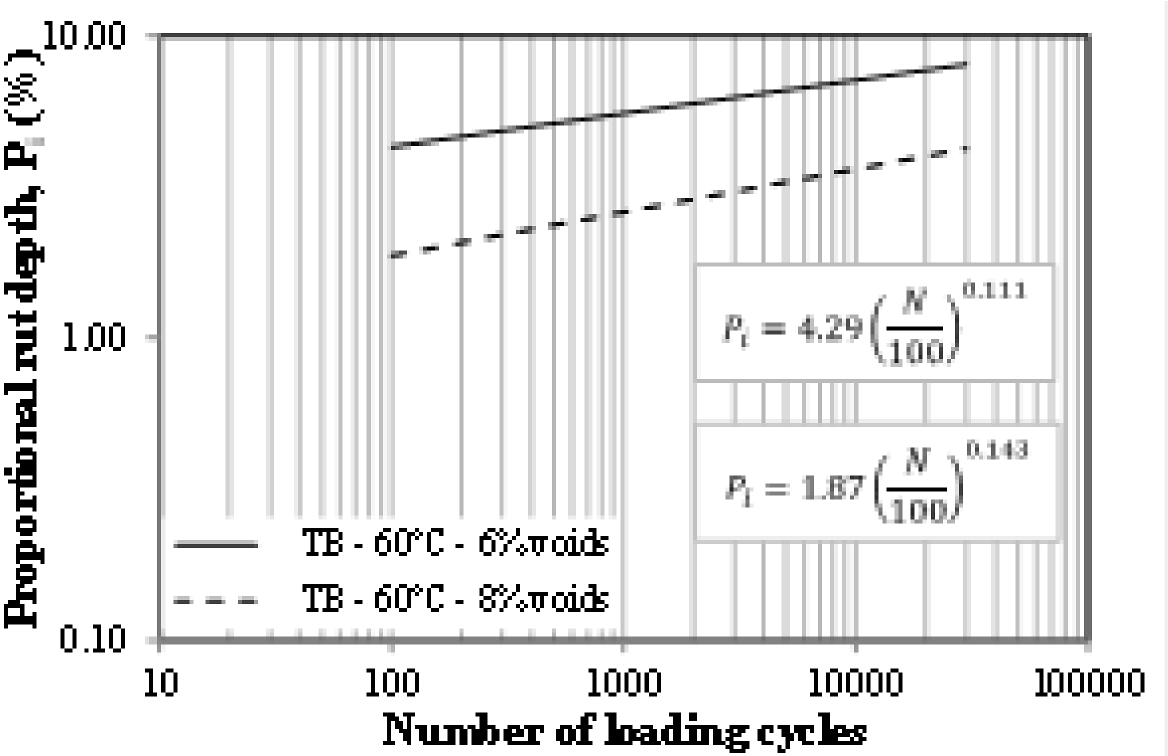
3.2: Characterization of bituminous mixtures

Test plan

	BV	TB	ZA	CE	SG	SD
Tests on aggregates						
Resistance to fragmentation	x				x	x
Flakiness index			x	x		
Shape index			x	x		
Tests on asphalt rubber binders						
Viscosity	x	x	x	x	x	x
Complex modulus and phase angle	x		x	x	x	x
Compaction tests						
Marshall	x	x	x	x		
Gyratory	x		x	x	x	x
Roller	x	x	x	x	x	x
Volumetric tests	x	x	x	x	x	x
Simple QA/QC mechanical tests						
Marshall stability and flow	x	x	x	x		
Indirect tensile strength	x					
Water sensitivity	x	x				
Performance-related mechanical tests						
Wheel-tracking	x	x	x	x	x	x
Semi-circular bending	x	x	x	x	x	x
Environmental tests						
Leaching	x		x	x		
Potential gaseous emission	x		x	x		

3.2: Characterization of bituminous mixtures

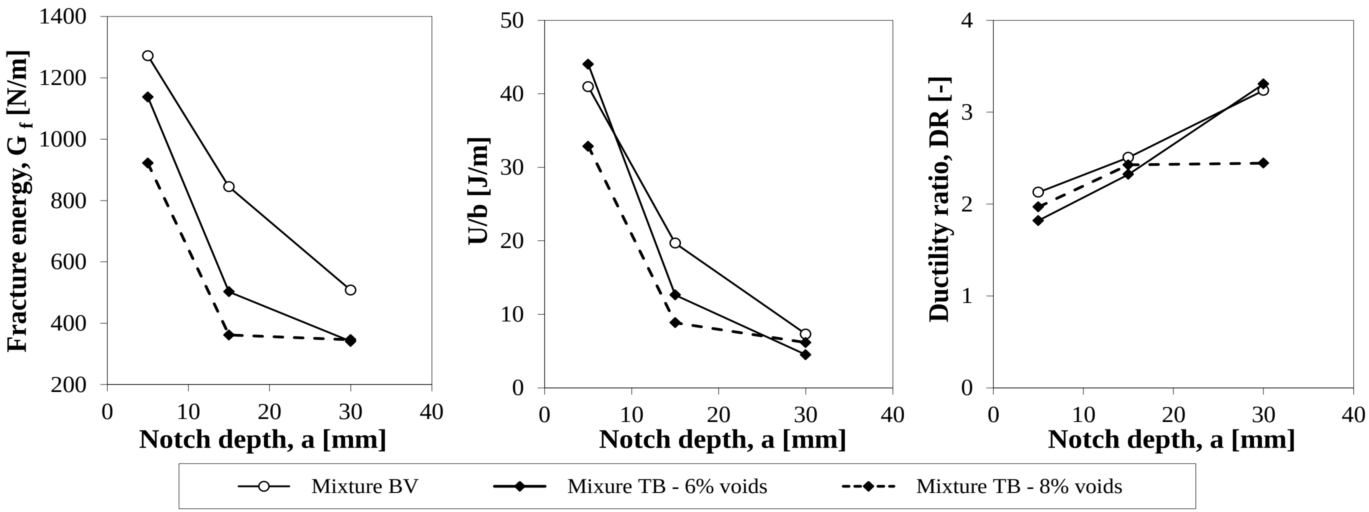
Wheel-tracking tests



3.2: Characterization of bituminous mixtures

Semi-circular bending tests

	%v [%]	G_{f0} [N/m]	DR_0 [-]	J_c kJ/m^2	ε_{max} [%]	K_{Ic} [N/mm$^{3/2}$]
BV	5.0	1373.77	1.88	0.92	-	-
TB	6.0	1163.85	1.49	0.98	-	-
TB	8.0	898.21	1.99	0.78	-	-
ZA	7.0	-	-	-	2.68	1.4
CE	10.5	-	-	-	1.60	2.7



3.3.1 & 3.3.2: Development and construction of a full-scale «dry» mixing prototype

1) **Preparatory activities** ⇨ **POLITECNICO & BRILLADA**
   - Literature review;
   - Technical survey.

2) **Preliminary design of the prototype** ⇨ **BRILLADA**
   - Assessment of current conditions;
   - Selection of additional components;
   - Layout definition.

3) **Laboratory screening study** ⇨ **POLITECNICO**
   - Analysis of the effects of production variables.

4) **Final design of the prototype** ⇨ **BRILLADA**

5) **Construction and validation**

3.3.1 & 3.3.2: Development and construction of a full-scale «dry» mixing prototype

3) Laboratory screening study

Evaluation of the optimal mode of use of CR in terms of:

- CR type **(2)**	→	"ultrafine" 0-0.4 mm
		"coarse" 1-4 mm
- CR dosage **(2)**	→	1% on weight of dry aggregates
		(+ reference mixtures with no CR)
- Type of bituminous mixture **(2)**	→	Base course
		Wearing course
- Mode of CR usage **(2)**	→	"hot"
		"cold"

3.3.1 & 3.3.2: Development and construction of a full-scale «dry» mixing prototype

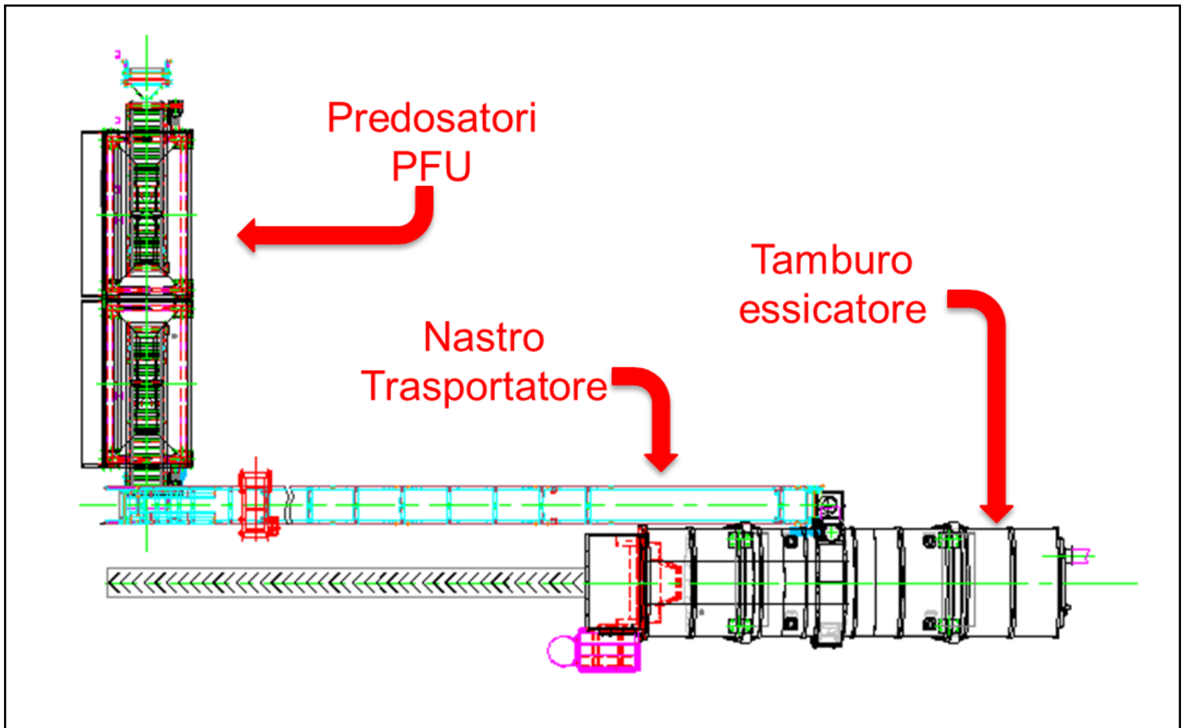
3) Laboratory screening study

Experimental activities:

- Selection and characterization of base materials
  - Aggregates 15/30 mm, 5/18 mm, 3/8 mm, 0/5 mm (Brillada)
  - Cement filler (Brillada)
  - 50/70 bitumen (Brillada)
  - CR (ultrafine and coarse): Tritogom (Cherasco)
- Optiimization of aggregate-filler mixtures;
- Identification of optimal bitumen dosage;
- Evaluation of compactability and elastic modulus.

3.3.1 & 3.3.2: Development and construction of a full-scale «dry» mixing prototype

4) Final design of the prototype (layout)



Elimination of the «cold» CR feeding option

4. Implementation actions

4.1: Full-scale test sections – Città Metropolitana di Torino

4.2: Full-scale test sections – Settimo Torinese

4.3: Pavement monitoring: skid resistance and roughness

4.4: Pavement monitoring: technical and environmental parameters

5. Life cycle risk assessment

- **SCOPE**
  Evaluate environmental effects of road construction (with CR).

- **SYSTEM BOUNDARIES**
  From the cradle to the grave:

  - CONSTRUCTION
    - EXRACTION AND RETRIEVAL OF RAW MATERIALS (aggregates, bitumen, ecc.)
    - PLANT ACTIVITIES AND MIXTURE PODUCTION
    - TRANSPORT OF MATERIALS
    - USE OF CONSRUCTION EQUIPMENT
    - LAYING AND COMPACTION
  - MAINTENANCE
  - END OF LIFE

5. Life cycle risk assessment

DATA

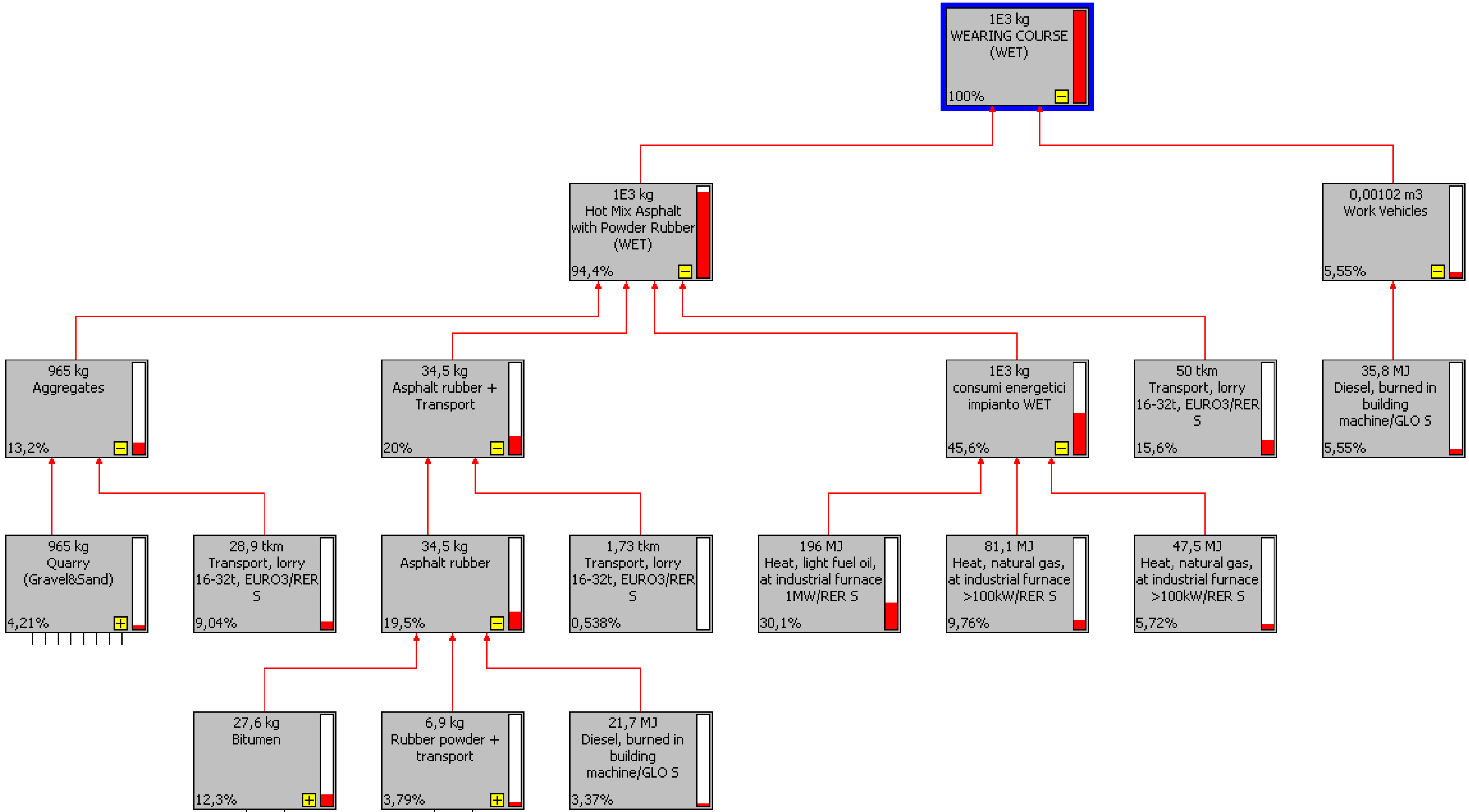
- ***Primary data***, directly collected on site.
- ***Data from literature*** and ***engineering hypothesese*** (where primary are lacking).
- ***Database***:
  - **Ecoinvent 2.2**, 2007 for electricity, fuel, materials (cement, water), transport
  - **Eurobitume**, 2012 (www.eurobitume.eu) for bitumen and emulsions.

5. Life cycle risk assessment

LIFE CYCLE INVENTORY (LCI):

- PAVEMENT
  - ***Geometry*** (length, width, layer thickness)
  - **Type and quantity of materials** [kg/m^3]
  - ***Life time***
- RAW MATERIALS
  - ***Origin***
  - ***Energy consumption [kWh/t]*** *for quarries and plants*
  - ***Type of transport***
  - ***Transport distances [km]***
- CONSTRUCTION, MAINTENANCE, END OF LIFE
  - ***Fuel for equipment [l]*** *(rollers, pavers, graders, milling machines, etc.)*

5. Life cycle risk assessment

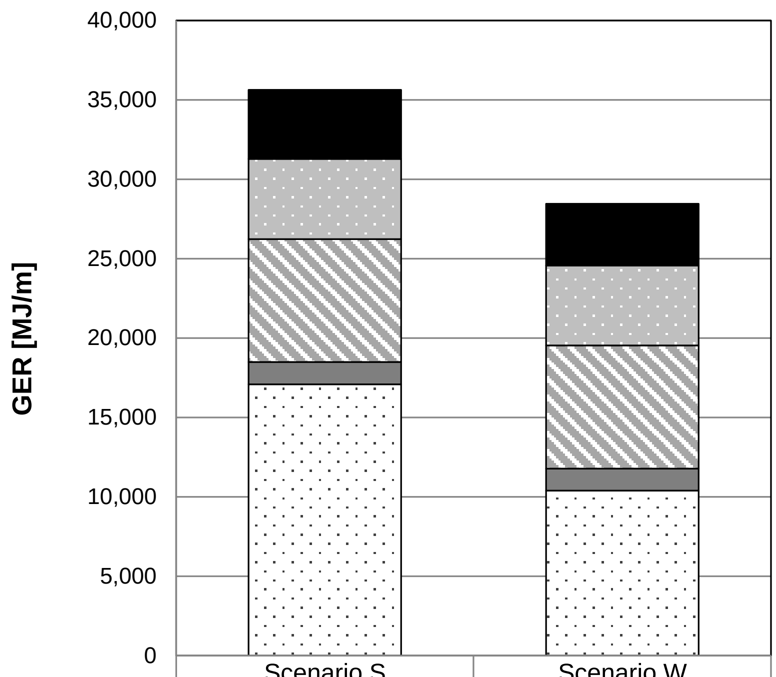


VALORI TOTALI	Scenario S	Scenario W
GER [MJ]	*35,618*	*28,500*
GWP [kg $CO_{2\ eq}$]	*1,110*	*869*

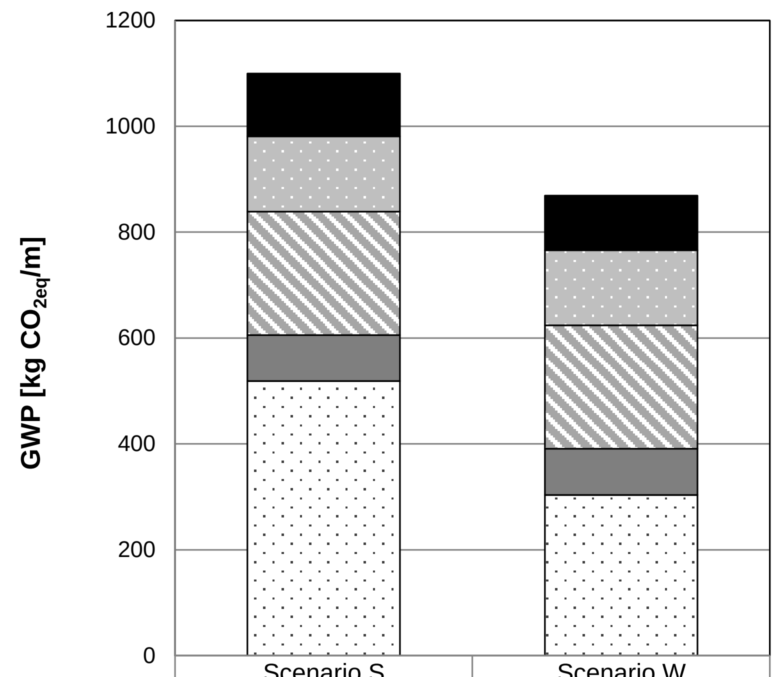
COMPARISON STANDARD-WET

Contribution of each layer and of maintenance to energy consumption and CO_2 emissions.

20% increase of environmental benefits



	Scenario S	Scenario W
Wearing	4,350	3,880
Binder	5,040	5,040
Base	7,750	7,750
Foundation	1,390	1,390
Maintenance	17,100	10,400



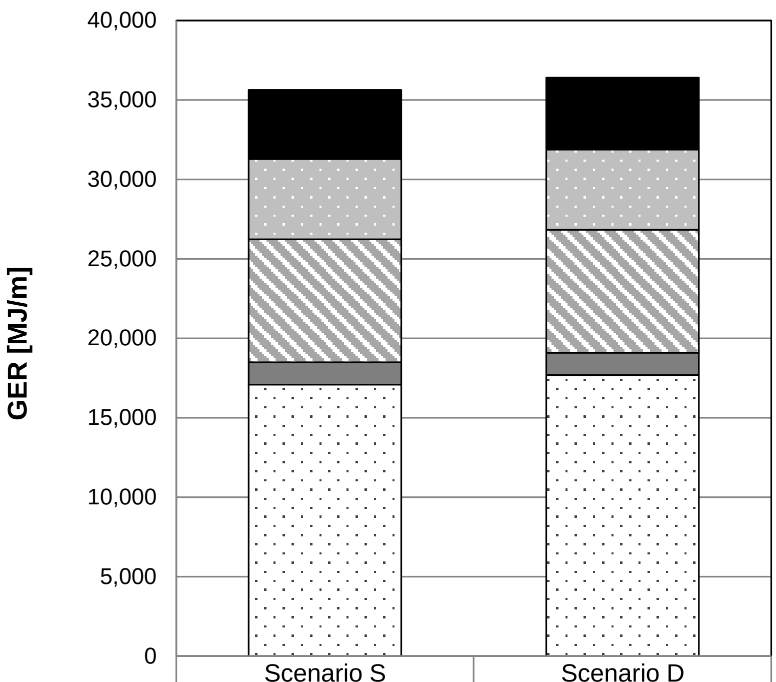
	Scenario S	Scenario W
Wearing	119	103
Binder	142	142
Base	233	233
Foundation	87	87
Maintenance	519	304

VALORI TOTALI	Scenario S	Scenario D
GER [MJ]	*35,618*	*36,887*
GWP [kg $CO_{2\ eq}$]	*1,110*	*1,102*

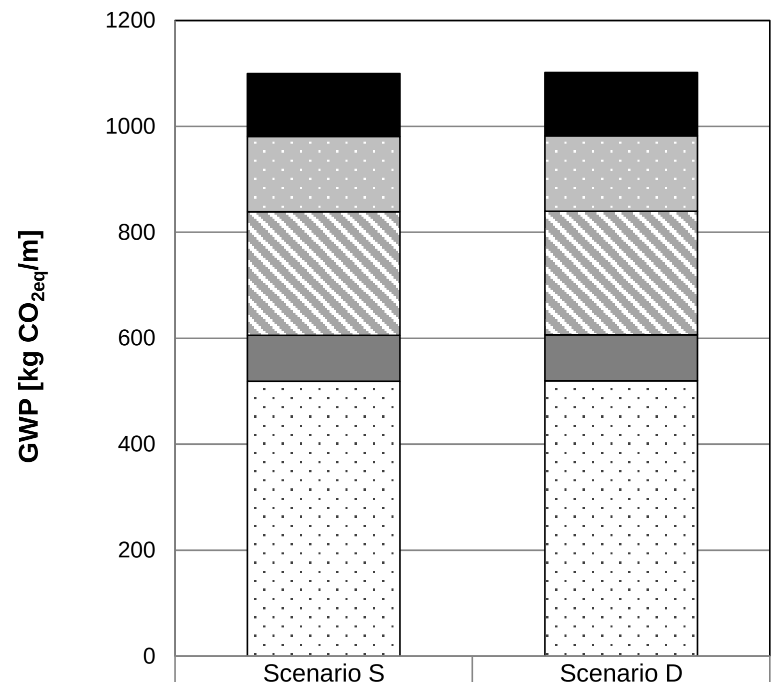
COMPARISON STANDARD-DRY

Contribution of each layer and of maintenance to energy consumption and CO_2 emissions.

NO RELEVANT DIFFERENCES



	Scenario S	Scenario D
Wearing	4,350	4,530
Binder	5,040	5,040
Base	7,750	7,750
Foundation	1,390	1,390
Maintenance	17,100	17,700



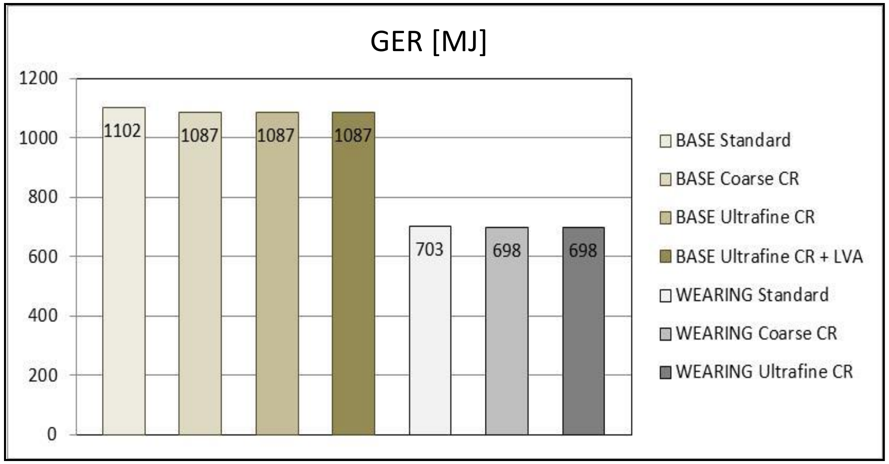
	Scenario S	Scenario D
Wearing	119	120
Binder	142	142
Base	233	233
Foundation	87	87
Maintenance	519	520

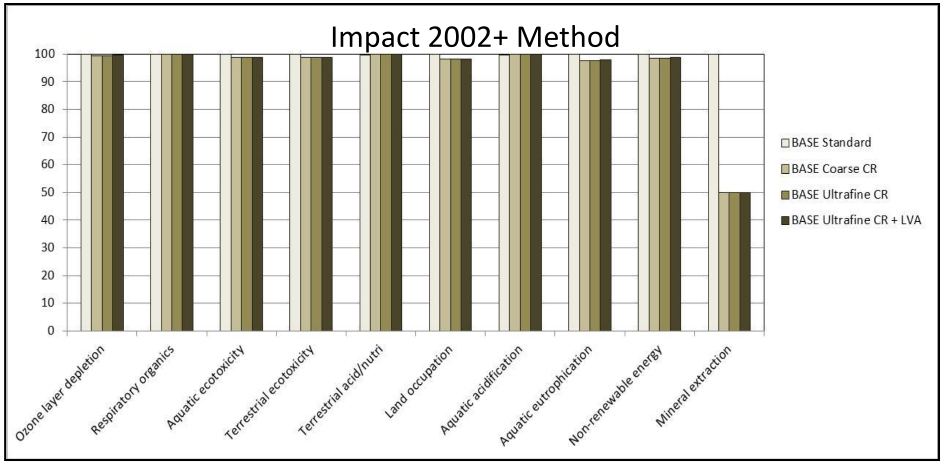
DEVELOPMENT AND IMPLEMENTATION OF INNOVATIVE AND SUSTAINABLE TECHNOLOGIES FOR THE USE OF SCRAP TYRE RUBBER IN ROAD PAVEMENT

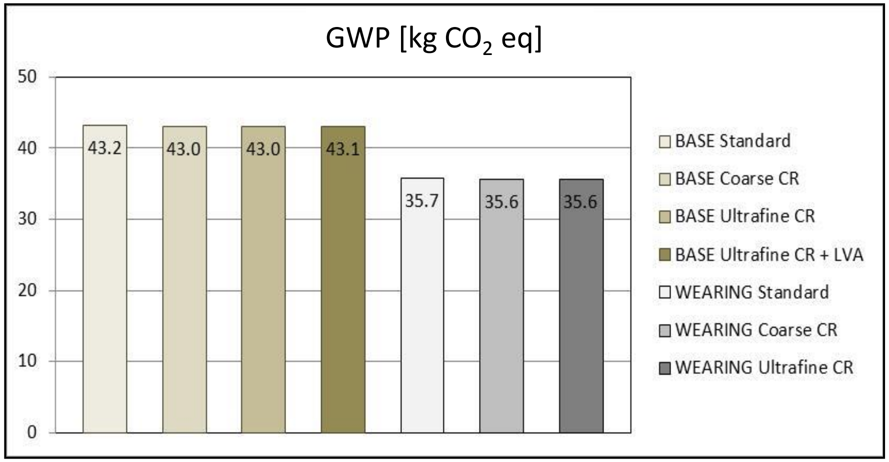
LIFE10 ENV IT 000390 « TyRec4Life »

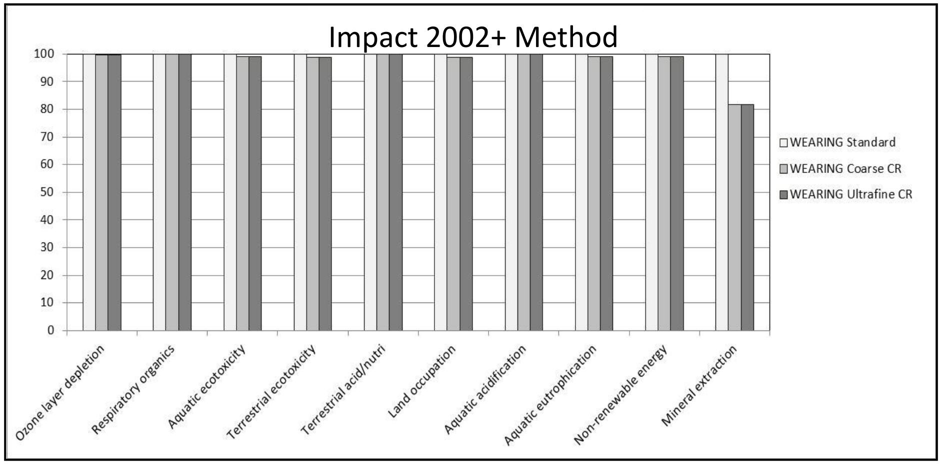
www.tyrec4life.eu

COMPARISON STANDARD-DRY (including low viscosity option)









Equal Environmental Impacts (GER, GWP and indicators of the Impact 2002+ Method)
Saving of raw materials («Mineral Extraction»)
Preliminary results (some energy assumptions)

Dissemination

Scientic publications

Technical reports and guidelines

Participation to Workshps and Conferences

Asphalt Rubber Study Tour

Thanks for your attention and for your interest in the TYREC4LIFE project