academicJournals

Vol. 8(10), pp. 562-581, October 2014
DOI: 10.5897/AJEST2014.1746
Article Number: D3FFC1D48526
ISSN 1996-0794

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Valorization of waste plastic bags in manufacturing of binders for bituminous concretes for road coatings

Kowanou Houénou, Sanya Emile Adjibadé*, Tchéhouali Dèfodji Adolphe, Dègan Gérard and Vianou Cocou Antoine

Laboratory of Applied Energetic and Mechanic (LEMA) Polytechnic School of Abomey-Calavi (EPAC) - University of Abomey-Calavi (UAC) 01 POB: 2009 COTONOU, Republic of Benin.

Received 18 June, 2014; Accepted 1 August, 2014

In 2012, Beninese landfills have quantified more than 12,000 tons plastic wastes with more than 50% of bags. The non-biodegradable nature of plastic generated an unprecedented environmental nuisance. The search for suitable solution led opting for partial recycling through construction processes. This article is devoted to characterization of new bituminous binders built of 50/70 graded bitumen to which is incorporated powder from molten waste plastic bags at 250-280 °C for road coatings/pavement. The analyzed parameters are binder's penetrability, softening point and adhesiveness, water absorption, and Marshall and Duriez stabilities of resulting bituminous concretes. The doped 50/70 graded bitumen, using plastic bags powder at 2-20% (wt/wt.mix), provided bituminous binders of better properties. The recorded results showed that the penetrability decreases when increasing plastic bags content, giving bituminous binders belonging to respective grades of 50/70, 40/60, 35/50, 30/45 and 20/30 followed by softening points increase. When the plastic bags content increased, better were these binders adhesivity. Similar trend was recorded for stability according to Duriez and Marshall on resulting bituminous concretes disclosing that the water absorption rate decrease. These obtained good performance characteristics should allow for significant reduction of the rapid degradation of classically coated roads, via extensive usage of waste plastic bags, then decongesting the established landfills here and there in Benin.

Key words: Waste plastic bags, bituminous binder, penetrability, softening point, adhesivity, stability; subsidence, bituminous concretes, water absorption rate, compacity.

INTRODUCTION

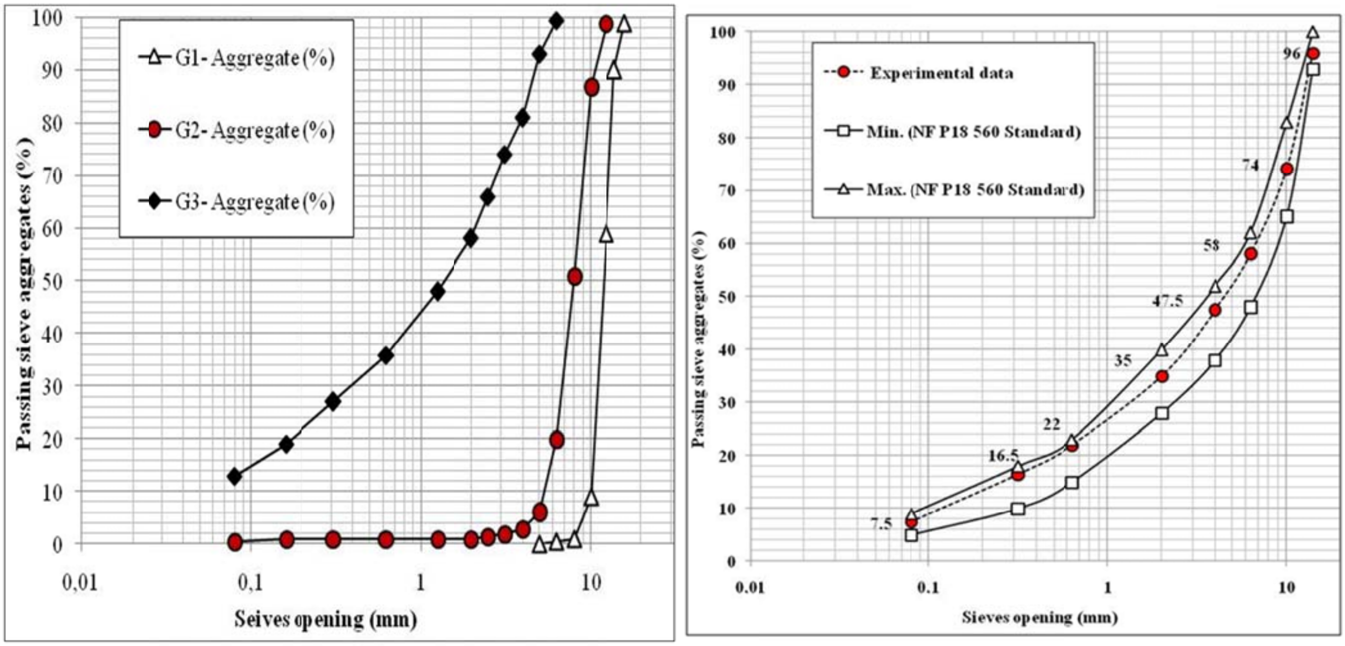
A current unpleasant observation, in Beninese cities and villages, is this obnoxious spectacle offered by waste plastics littering the streets and verges, shallows and near watercourses, municipal or spontaneous landfills and other locations or reserved places for entertainment. Several studies, either sponsored (MEHU, 2002; Lawson et al., 2008) or academic works here (RNCR, 2011; Gbèdo, 2009) and elsewhere (Ghernouti and Rabehide,

*Corresponding author. E-mail: easanyas@gmail.com.

2009; Yazoghli-Marzouk et al., 2005; Kapil and Punjabi, 2013; Vasudevan et al., 2007; Huang et al., 2007; Verma, 2008; Prasad et al., 2009), have raised this subject which became almost unbearable. According to a report from Benin Network of Resource Centers of November 2011, about 86% of the waste plastic bags are thrown on streets after use, 5.50% incinerated, 5.50% as source for cooking fire and 2.75% for various other purposes (Gbèdo, 2009). Due to the non-biodegradable nature of plastic which can withstand service life for more than 50 years, as it's said: "The plastics can stay unchanged for as long as 4500 years on earth" (Behjat et al., 2014), the recycling way, based on modern techniques, is now proving indispensable to achieve secure, healthy and sustainable environment as well, in Benin Republic, as in most of south Saharan countries. However, in majority of countries affected by this problem, technical and financial resources that could help ensuring, even a classic recycling, are practically nonexistent. Some countries, including more recently Cameroon Republic, have audaciously decided to forbid importation of non-biodegradable plastic bags. One of the identified ways as relevant to efficiently promote the waste plastics is their use in the processes of public infrastructures construction. In field, very little (almost or no) serious scientific investigations have been devoted to such recovery track in Africa. Elsewhere at contrary, fairly recent studies exist (Ghernouti and Rabehide, 2009; Yazoghli-Marzouk et al., 2005; Kapil and Punjabi, 2013; Vasudevan et al., 2007; Huang et al., 2007; Verma, 2008; Prasad et al., 2009; Behjat et al., 2014; Bindu and Beena, 2010; Khan et al., 2009; Punith and Veeraragavan, 2007; Panda and Mazumdar, 1999; Kalantar et al., 2010; IRC, 2001). Among these, can be included the one that proposed the recycling of waste plastics as incorporated materials for reinforcing the infrastructures construction, as well, for hydraulic mortars and classical concretes, after being properly conditioned by cutting them into fine particles (Afroz Sultana and Prasad, 2012; Ghernouti and Rabehide, 2009; Yazoghli-Marzouk et al., 2005), as for the bituminous concretes and paving stones for roads surfacing (Kapil and Punjabi, 2013; Jain et al., 2011; Vasudevan et al., 2006; Huang et al., 2007; Kalantar et al., 2010; IRC, 2001). The obtained results by Yazoghli-Marzouk et al. (2005) showed that the mechanical and hydraulic resistance of mortars and concretes, the water absorption and thermal conductivity decreased as incorporated percentage of plastic wastes was increased: from 2 to 50%. The method has the merit of proving the beneficial effects concerning the possibility for using plastic wastes, in large quantities in site of construction and postulating it's attractive in terms of cost (Yazoghli-Marzouk et al., 2005). Moreover, the waste plastics have been used alone (between 10 and 30 %) for coating aggregates or in combination with 80/100 bitumen class (between 1 and 10%) or mixed with tyres powder (from 1 to 5%) in the implementation of pavements coating (Vasudevan et al.,2007). The reached results allowed the authors concluding to an increase in compressive strength and flexural strength of the obtained composites, but embedding a higher plastic content in bitumen, is not favorable. In Benin Republic, first attempts for thermally processing of the waste plastics date back a decade and are attributed to BETHESDA non-governmental organization (NGO) which has experienced pavements manufacturing by incorporating the melted waste plastics. More recently, laboratory tests were performed for mechanical characterization of a composite material made of wood-sawdust bound in mixture with molten plastic for woody furniture production (Doko, 2013). Ultimately, the largest volume of plastic bags will fail daily in municipal or spontaneous landfills where they are mixed with various other wastes. Populations have a habit of removing much for backfilling the shallows before becoming established. Farmers found that the waste plastics boots act to seal soils making them unfruitful, due to the significant decline in water infiltration that they cause. This article is devoted to study the influence of incorporation of the powder, obtained from melted of the extracted waste plastic bags from dumps/landfills, cooled and finely ground, on the performance classical characteristics of the bituminous binders and the derived concretes, chiefly their penetrability index, softening point, adhesivity, stability according to Duriez and Marshall, and slump/creep flow (Duriez and Arrambide, 1959; Jeuffroy, 1978). This choice was made in perspective of an incentive for eco-recovery, through a quantitative usage of waste plastics in construction processes (flexible pavements and other concrete infrastructures). This should contribute to a significant reduction of this established bane by proliferation of non-biodegradable waste plastic bags in Africa.

MATERIALS AND METHODS

Materials which were the tests subject reported in this article are categorized as they follow. However, the main material was the waste plastic bags, of black color. This choice is guided by the intended use but also by color compatibility with that of used conventional 50/70 graded bitumen in construction of the roads in Benin. Thus, the used waste plastic bags surely belong to one or another of the following six (06) dominant marks from those consumed many variants on the Beninese markets: Induplast (Togo), Africa 24 (Togo), Eagle (Togo), Le nouveau (Ivory Coast), Sunshine (Benin) and Cheval (Benin). Truly employed waste plastic bags are from all comers category, but black. They consist essentially of materials made of low-density polyethylene (LDPE) that belongs to linear or branched chains thermoplastic polymers class obtained from additive reactions. The LDPE is built of interconnected macromolecules by low intensity Van der Waals or hydrogen bonds connections often represented by $(-CH_2-CH_2-)n$. Its molecular weight is about 7,000 $g.mol^{-1}$ and density 0.92±0.01 $g.cm^{-3}$. The LDPE overall behavior thus depends on chains mobility relative to each other and C-C bonds rotation. Under the heat action, thermoplastics, especially LDPE, melts/softens and recovers its rigidity on cooling and this mechanism is reversible. This LDPE main property, qualified elsewhere as high thermal extension but



a b

Figure 1. Particles size of the used aggregates and location in relation with the recommendations of NF P18-560 standards (Editions, 1997): two extreme curves a. Particles sizes of aggregates G1, G2 and G31. **b.** Used aggregate mix particles size.

low stiffness (Afroz-Sultana and Prasad, 2012), has been exploited in current investigation. In practical manufacturing of LDPE plastic bags, many different additives are often added, depending on manufacturers and desired properties to be conferred on the produced bags. Similar additives were applied to derived products from high density polyethylene (Moatasim et al., 2011).

For the various tests, for penetrability and ring and ball softening point, the materials consist of 50/70 graded bitumen (as control) designated by M0 on one hand|", and to this same 50/70 bitumen to which was added the powder of the melted waste plastic bags at respective contents of 2, 4, 6, 8, 10, 12, 15, 18 and 20% by weight of bitumen (partial substitution) on the other. These binder mixes were respectively identified by M_1 (as mixture 1 for 2%), M_2 (as mixture 2 for 4%) to M_9 as shown. For adhesivity assays, the used materials are those from the binder mixtures M_0, M_1, M_2, M_3, M_4, M_5 and the obtained fines from crushed aggregates of sizes between 0.2 and 0.5 mm that displayed an absolute density of 2,690 kg/m^3.

For Duriez and Marshall respective tests, the involved materials were the crushed granite that has been divided into three (03) gradings [G_1 of φ=10/14, G_2 of φ=6/10) and G_3 of φ=0/6] as shown in Figure 1.

The used sieve series belongs to that of French Standards Association (AFNOR). Openings and different percentages of theoretically expected sieves passing are shown in Table 2.

The really used aggregate derives from a made reconstitution based on the three different aggregates (G_1, G_2 and G_3) having particles size distribution structures are disclosed in Figure 1a. This reconstitution is carried out according to the recommended grading ranges by P18-560 standards as shown in Figure 1b. One can observe that the particles size distribution of the resulting aggregate (Figure 1b) is in effect well integrated within the established range for normalized particle sizes. This aggregate contains, in weight percentage, 25% of aggregate class G_1, 20% of aggregate class G_2 and 55% of aggregate class G_3. The average absolute density of these aggregates is 2,690 kg/m^3.

Procedure for preparation of powder from the waste plastic bags

The adopted method in development of the new bituminous binder is first to melt the waste plastic bags in a suitable metal container protected against free air (oxygen) entrance. The melting process was methodically carried out with monitoring of operative temperature of 250-280°C (max). It's known that, polyethylene ignition temperature and particularly decomposition, as those of most plastic materials, occur between 300 and 350°C (Vasudevan et al., 2007). Temperature recorder TESTO (0-1000 °C, 4 outputs) equipped with K-type thermocouples was carefulness used in this regard. In Figure 2 is shown an example of acquired typical kinetics in terms of temperature during the melting and cooling phases of the powder preparation cycles from waste plastic bags. In reality, the used waste plastic bags are already melted between 200 and 275°C. This obtained liquid plastic was therefore allowed to cool in ambient air, at temperature of 29-31°C and relative humidity of 67-73%. The derived solid was then finely ground into powder for passing the 0.160 mm normalized sieve. For this, crushing and grinding of the platelets of molten waste plastic bags was operated with electromechanical miller of Ding Mill n°2A type, the same classically employed for milling of agricultural grains.

Development of the proposed new bituminous binders

Nine (09) different bituminous binder mixtures indexed as M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8 and M_9 were developed (Table 1). They were made from incorporation of powder from the melted waste plastic bags, cooled and finely ground to reach particles of 0.160 mm mean diameter, in partial substitution into the chosen 50/70 graded bitumen (as main binder carrier) for all the designed bituminous binders. The explored powder rates for the melted waste plastic bags are respectively of 2, 4, 6, 8, 10, 12, 15, 18 and

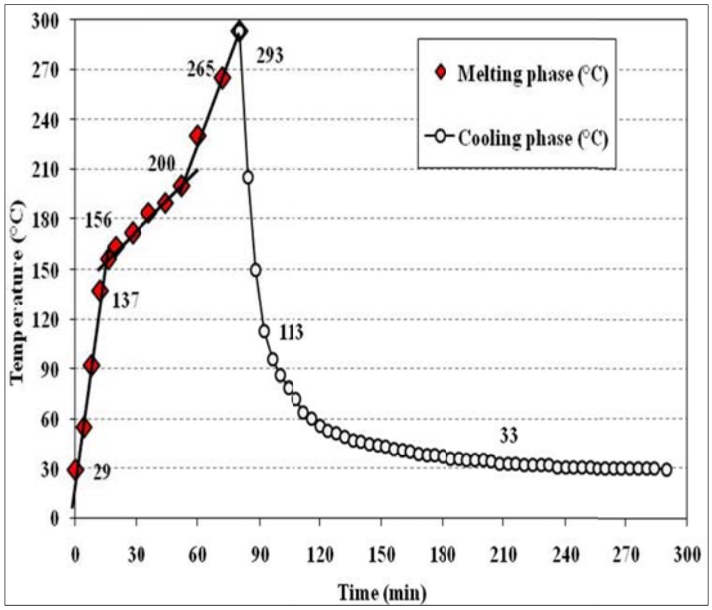


Figure 2. Recorded kinetics during the melting and cooling phases of waste plastic bags.

Table 1. Adopted percentages for constituents of tested bituminous binders mixes'.

Constituent (%)	Adopted formulation in realizing the bituminous binder mixes									
	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
Bitumen *	100	98	96	94	92	90	88	85	82	80
PMWPB **	0	2	4	6	8	10	12	15	18	20

*50/70 graded bitumen; ** PMWPB, Powder of melted waste plastic bags.

Table 2. The used sieves series from AFNOR Standards and optimal theoretical granulometry.

Parameter	Value							
Sieve opening (mm)	16	14	12.5	10	8	6.3	5	4
Percent passing (%)	100	96.5	89.5	74	65.5	55	52.5	45
Sieve opening (mm)	3.15	2.5	2	1.25	0.63	0.315	0.16	0.08
Percent passing (%)	41	36.5	34	26.5	19	15	10.5	7

20% (wt/wt.mix), that of 0% corresponding to the bituminous binder made of pure reference 50/70 graded bitumen taken as control/witness and indexed M_0 (that is without any plastic bags powder).

The mixing of the obtained powder from the melted waste plastic bags with the chosen 50/70 graded bitumen is carried out at hot conditions: mixture temperature of 165±5°C. Preliminary investigations devoted to mastering of the optimized speed and spending time show that the use of oven-dryer at 165°C with electromechanical agitator as mixer constituted the best means for blending the grading 50/70 bitumen in progressively incorporating the powder from melted waste plastic bags. The optimized conditions were attained at relatively low speed 115±3 rpm and 18±2 min from moment it's ensured that the 50/70 graded bitumen has entirely melted. However, trials have also been unsuccessful conducted in view of direct combining molten plastic bags to molten bitumen. The main difficulties are due to maintaining and direct mixing of fused plastic bags at melting higher temperature (250-270°C) than required for bitumen.

Procedure in measuring binder's penetrability

The penetrability test is performed in accordance with the procedure of EN-1426 standards. Its realization consists of releasing, for 5 s, a standardized 1.0 mm diameter needle submitted to 100 g-loading and then measuring the depth (in tenths of millimeter) to which the needle penetrates into a previously

Figure 3. Ring and Ball standardized testing device used for softening point measurements.

cooled bitumen (or bituminous binders mix) and maintained water immersed at temperature of 25°C and just released for this test. Penetrability Index is a quality control parameter (hardness) used for defining the class/grade of bitumen or bituminous binder in roads construction (Kapil and Punjabi, 2013; Khan et al., 2009; Punith and Veeraragavan, 2007; Panda and Mazumdar, 1999; Jeuffroy, 1978; BCEOM-CEBTP, 1975). The used bitumen, as witness (or control), in this work and for which the determined grade a priori corresponding to 50/70, was first subjected, alone (thus assumed pure), to all the realized tests, in view for protocol validation. From then on, the same tests were subsequently carried out on each the nine (09) different constituted variant mixtures M_1 to M_9 binders from incorporation of the powder from the melted waste plastic bags at mentioned percentages above.

The material used is conformed to that prescribed in procedure of the NF-EN-1426 standards which comprises basically: DOW brand CONTROLAB penetrometer, range values from 0 to 36 mm and its accessories; stem type thermometer range of 0 to 200°C, for monitoring the temperature of the control in view of retaining dome to the constant value equal to 25°C; stopwatch to measure the time of loading of the samples; sensitive balance to hundredth of a gram, to weigh bitumen and different proportions of realized plastic bags powder; large dimensions basin of water, devised for immersion testing of specimens; refrigerator for ice cubes producing to be used when checking thermocouples calibration; climatic chamber for maintaining or regulating the tests temperature constant to 25°C as prescribed.

Determination of the binders softening points

Measurement of binders softening points is made, by Ring and Ball method, according to the procedure of EN-1427 standards. The principle consists on searching for the temperature value at which any bitumen or other binder achieves a conventionally established consistency. The required equipment for this measure is the compulsory EN-1427 standards shown in Figure 3 presenting the ring and ball device used for this purpose. It comprises essentially: glass plate devoted to polish the two faces of the placed samples in rings using petrolatum; sand bath providing, without any direct contact between the glass jar and fire, the required heat that allowing for temperature of the water that housing the rings, beads and samples, to gradually rise without exceeding a rhythm of 5°C per minute; stem thermometer, range 0 to 200°C, allowing continuous monitoring of temperature evolution; refrigerator, for ice production, ice used each time for reducing or regulating the device temperature in order maintaining rate value of 5 °C at the beginning of every test; and gas stove, for melting bitumen and filling rings on one hand and maintaining sand bath temperature, on the other.

As theoretical 50/70 graded bitumen softening point is known (EN-1427), the really acquired bitumen, as the witness/control in our done various experiences in this study, was first tested. Afterward, we became interested in the nine (09) bituminous binders M_1 to M_9 formed from different powder concentrations previously cited above.

Riedel and Weber testing method for binder's adhesivity determination

The Riedel and Weber test is performed following the procedure of NFT66-018 standards. This measurement is based on pellets of bituminous concretes, having mass of 0.50 g, formed from a bituminous binder and a crushed sand of very fine granular class (sizes 0.2/0.5 mm). These bituminous concretes in reality, are made by mixing, at appropriate temperature, 71 (mL or cm^3) of aggregates and 29 (mL or cm^3) of binder (made of control 50/70 graded bitumen only or one coming from the mixture of bituminous and plastic bags powder). The test consists of immersing the pellets of a bituminous concrete in the prepared respective solutions of sodium carbonate, at increasing concentrations (S_1 to S_9) in order to assess for separation degree (adhesivity encoded value) corresponding to concentration at which the binder is completely separated from aggregates. When the stripping starts at a certain concentration on a given pellet and becomes total at another concentration with another pellet, one retains as odds values, these odds corresponding to both the two concentrations scoring partial stripping and total stripping. For example, the odds value 3-5 means that the stripping began with S_3 solution and was complete with S_5 solution. According to normative provisions, the final odds values from 1, 2, 3 to 4 display a sufficient adhesivity, those going from 5, 6, 7, 8, 9 to 10, correspondingly, a good adhesivity and a very good adhesivity (Duriez and Arrambide, 1959). The specifications of each project should clarify the indispensable odds values (Jeuffroy, 1978; BCEOM-CEBTP, 1975). Used materials in this experimental measurements series are consistent with those for NFT66-018 standards and comprise mainly the following accessories: sensitive to hundredth a gram laboratory balance, Sarthorius type, for weighing the pellets to be tested: prescribed mass for samples, approximately 0.50 g; gas stove, for melting the 50/70 control bitumen, devised binders and also heating aggregates; Benson gas burner, for bringing the sample's carrier solution to boiling; graduated test tube, for measuring volume of other materials and another graduated test tube, arranged so that the sample, in its solution step of 6 cm^3, can be brought on Benson gas burner for the normal duration of 60s, beginning from the boiling point; stopwatch, for tracking latency time set at 60 min and that of test of 60s; and distilled water and various accessories of which is the wood clamp, and the chemical reagents like different aqueous solutions of sodium carbonate (Na_2CO_3). Ten (10) solutions of sodium carbonate were prepared and indexed from S_0, S_1 to S_9 corresponding to concentrations ranging from 0 g/L of distilled water (control/witness), 0.414, 0.828, 1.656, 3.312, 6.625, 13.25, 26.5, 53.0 to 106.0 respectively. The control 50/70 graded bitumen (M_0) was first tested and from then on, the different variants of bituminous binder ensuing from incorporation of powder of melted waste plastic bags at different cited percentages and their decoulant bituminous concretes.

Table 3. Tested points in searching for optimal value of the being used binder content.

Experimented values of binder content P (%) from the determined interval (4.88%, 6.5%)										
P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
4.8	4.9	5.1	5.3	5.5	5.7	**5.8**	5.9	6.1	6.3	6.5

Procedure in measurement of Marshall' stability

The test consists of compacting samples according to a defined process and then subjecting them to compression test. The used material is conformed to that prescribed by NF P98-251-2 standards. It essentially comprises of: a Marshall press brand IGM, Marshall molds and Marshall compactor (setup in this study for operating at 50 cycles), a balance of 500 g hundredth of a gram sensitive and a balance range 4000 g sensitive tenth of a gram, a stem thermometer of range 200°C, and a mercury thermometer of range 150°C, an oven-dryer of range 250°C, a stopwatch, a gas stove and a 80L thermostatically bath adjusted to 60°C.

The proportions of various constituents of bituminous mixture were determined following the formulation from a tests series to meet the set convergence criteria (stability, compactness and creep) fixed by specifications wrote by the project manager to finally evaluate the optimal dosage of each of the said constituents.

Achievement of Duriez tests

The main object of Duriez test is to characterize the quality of the coated materials in terms of mechanical strength on the one hand and their resistance against water stripping, on the other. It is applied to bituminous coated materials and aggregates which pass entirely square mesh sieve of 20 mm. The taken sample is introduced in only one time into the glycerin pre-coated molds. The full molds pass a stay of 30 min in oven-dryer regulated to 160°C. The applied compacting load is 60 kN. This charge is maintained for 300 s. The specimen is removed from the mold after staying 240 min; time allowed to reach, by cooling at open air, the ambient temperature. During the first 24 h after manufacture, the samples are stored in a climatic chamber at constant set room temperature of 18°C. Two (02) of samples are devoted for measurements of hydrostatic bulk densities, four (04) to conservation without immersion and the remaining two (02) others to water immersion conservation. Conservations were performed in an atmosphere temperature of 18°C and relative humidity of 50%±10% by following procedure of the NF P98-251-1 standards.

Formulation of a bituminous concrete

Determination of to test materials composition (NF P98-251-1)

The formulation of a bituminous concrete, dedicated to specimens confection for Duriez and Marshall tests, is commonly carried out on the basis of values of the relevant parameters such as conventional binder richness modulus (M_{RB}), aggregates specific surface (β) and absolute density (ρ_{AG}). The conventionally adopted specific surface (β) is determined, at first approximation, from relationship (Duriez and Arrambide, 1959):

$$100\cdot \beta = 0.25\cdot g + 2.3\cdot S + 12\cdot s + 135\cdot f \qquad (1)$$

Where, β is the aggregate of specific surface, (g) percentage of granulates greater than 5 mm diameter, *S* aggregates percent having diameters between 0.315 and 5 mm, *s* aggregates percentage having diameters between 0.08 and 0.315 mm and (*f*) aggregates percentage having diameters smaller than 0.08 mm.

For this calculation, referring to Figure 1b, value of aggregates specific surface is, in case of this study, as β=12.2645 m²/kg. The binder richness modulus (M_{RB}) is a very important characteristic. As it is said, the "Binder richness controls the flexibility of coating". It should be, neither too low, nor too high. Its value ranges between 3.50 and 3.75 in France, but can attain 6 for some non-road facilities (Duriez and Arrambide, 1959). For hot climate countries, case of Benin Republic, the prescribed values for binder richness modulus range from 3 to 4 (BCEOM-CEBTP, 1975) and 3.50 to 3.80 for high traffic roads (Coquand, 1975). We have then chosen to test the larger range values from 3 to 4 recognized to be convenient for hot climate countries (BCEOM-CEBTP, 1975). The binder content value to be considered (P%) is function of both two quality control characteristics (the binder richness modulus M_{RB} and the aggregates specific surface β) and can be determined using the following formula:

$$P = M_{RB}\cdot \sqrt[5]{\beta} \Leftrightarrow \log P = \log M_{RB} + (1/5)\cdot \log\beta \qquad (2)$$

The maximal binder content (P_{Max}) is derived from equation (2) by substituting maximal value of binder richness modulus (M_{RBmax}) where M_{RBmax}=4 and the previous value of aggregates specific surface (β). This leads to maximal value of binder content of P_{Max}=6.6%.

The same calculation procedure was applied to minimal value of binder richness modulus (M_{RBmin}) where (M_{RBmin})=3 giving P_{Min}=5.0%.

The normalized aggregates absolute density (ρ_{AG}) being 2.65 and the truly used aggregates absolute density (ρ_{EG}) in case of our tests 2.69, it is then necessary to apply a correction to this obtained binder content (P%) and consequently to P_{Max} and P_{Min}. The correction factor (k), calculated as the ratio of conventional absolute density to effective absolute density, is equal to:

$$k = \rho_{AG} / \rho_{EG} = 2.65/2.69 = 0.985$$

Thus, the corrected minimum and maximum binder contents $P_{Min,cor}$ and $P_{Max,cor}$ become:

$$P_{Max;cor} = 6.6\cdot k = 6.6\cdot 0.985 = 6.5\,\% \qquad (3)$$

$$P_{Min.cor} = 5.0\cdot k = 5.0\cdot 0.985 = 4.88\% \qquad (3')$$

Therefore, from these corrected values of minimum and maximum binder contents giving rise to interval [$P_{Min,cor}$, $P_{Max.cor}$]=[4.88%, 6.5%], the binder contents that must truly be experienced were determined. To reach the latters, interval [4.88%, 6.5%] has been arbitrarily divided by adopting a sampling step which allows for obtaining 11 experimental points, with finer resolution mainly around the sketched optimal point. This has led to tested different values of the binder contents (P %) gathered in Table 3.

Table 4. Proportions of aggregates (types G, Sizes φ) and 50/70 graded bitumen with corresponding masses (g) in mixes giving the tested bituminous concretes.

Binder's optimal rate in mix (%)	Aggregates total mass in the mix (g)	Aggregates G_1 φ (10-14)	Aggregates G_2 φ (6-10)	Aggregates G_3 φ (0-6)	Bitumen 50/70 mass (g)	Mixture total mass (g)
		25%	20%	55%		
6.5	1127	282	225	620	73	1200
6.3	1129	282	226	621	71	1200
6.1	1131	283	226	622	69	1200
5.9	1133	283	227	623	67	1200
5.8	1134	284	227	623	66	1200
5.7	1135	284	227	624	65	1200
5.5	1137	284	227	626	63	1200
5.3	1140	285	228	627	60	1200
5.1	1142	285	228	629	58	1200
4.9	1144	286	229	629	56	1200
4.8	1145	286	229	630	55	1200

Table 5. Proportions and masses for bituminous concrete constituents in Duriez tests

Bituminous concrete composition at binder content of 5.8 %				
	Type G - Size φ	**Percentage (%)**	**Partial mass (g)**	**Mass (g)**
Aggregates:	G_1 - φ (10/14)	25	236	
	G_2 - φ (6/10)	20	189	**945**
	G_3 - φ (0/6)	55	520	
Bitumen:	50/70	**5.8**	55	**55**
Total mass of bituminous concrete (g):				**1, 000 g**

State the parameter for the values highlighted (Partial mass (g) corresponding to different cited percentages).

Determination of bituminous concretes composition

Total mass of the components to include in the Marshall mold, according to NF P98-251-2 for each batch, is 1,200 g. The mass of aggregates (M_{AG}) to be considered is determined on basis of the binder content (P %) using the formula (Duriez and Arrambide, 1959; BCEOM-CEBTP, 1975):

$$M_G = (100 \cdot 1{,}200)/(100 + P) \quad (4)$$

Application of relation (4) leads to the listed values for proportions of both two used constituents (aggregates of type G and size class φ; 50/70 graded bitumen) of bituminous concretes (Table 4).

Theoretical binder contents were estimated and then used to prepare various samples of bituminous concretes subjected to tests. Classical control characteristics from realized tests, as Marshall' stability, apparent density, compactness and creep, allowed determining the bitumen optimal content. This binder ratio, identified from previous experiences as being the best, has served for calculating the respective masses of components for the different bituminous mixtures subjected to Duriez tests. Then, the retained optimal composition of bituminous concretes was disclosed in Table 5.

It should be mentioned, in this regard, that the Duriez mold only admits 1,000 g of material in case of the aggregates mixtures which larger diameters less than 14 mm (NF P98-251-1 standards) compared to Marshall's mold containing 1,200 g.

Doping of bituminous binder involves the incorporation that is replacing, weight for weight, a known percentage of the chosen 50/70 graded bitumen as control, by powder from the melted waste plastic bags. In reality, four (04) rates of dope (powder from melted plastic bags) were analyzed in partial substitution to 50/70 bitumen in the studied bituminous binders and their derived concretes. The explored powder percentages from the melted waste plastic bags are respectively of 0, 4, 8, 12 and 20% (wt/wt.mix), the (0% wt/wt. binder mix) bituminous concrete corresponding to non doped 50/70 graded bitumen (as control), thus being a total of explored five (05) points in this series of effected experiences. In Table 6 are gathered constituents corresponding masses of different binder mixes percentages for various tested Asphalt concretes specimens for Marshall and Duriez testing methods.

Processing and analysis of the recorded data

The acquired data from those different realized experiments were statistically processed using Microsoft Excel software 2010 editions. It allows analysis, exploration and identification of the mathematical models that describe the behaviors of recorded data and corresponding trends' curves.

RESULTS AND DISCUSSION

Results from penetrability measurements on the selected binders

The recorded data during penetrability tests are summa-

Table 6. Summary of Asphalt concretes mixes as function of plastic bags powder percentages.

Asphalt concretes constitution at binder optimal rate	Powder percentages and corresponding values in used binder mixes total mass for tests in:												
	Unit	Marshall method						Duriez method					
Binder optimal rate	%	**5.80**											
Aggregates total mass	(g)	1,134						945					
Plastics rate in binder	%	0	4	8	12	20	100	0	4	8	12	20	100
Bitumen 50/70 mass	g	66	63.36	60.72	58.08	52.8	0	55	52.8	50.6	48.4	44	0
Plastics powder mass	g	0	2.64	5.28	7.92	13.2	66	0	2.2	4.4	6.6	11	55
Binder mix total mass	g	66						55					

State the meaning of these highlighted (5.80%: binder optimal rate; 1,134 g and 945 g: aggregates total mass in Marshall and Duriez methods; 66 g and 55 g are respective binder mixes total masses in 1,200 g and 1,000 g samples' masses).

Table 7. Results from penetrability tests for the constituted bituminous binders' mixtures.

Tested Bituminous binders' mixtures	Powder from melted of waste plastic bags contents (% w/w.mix)	Measured Penetrability values ($x10^{-1}$ mm)						Obtained range values ($x10^{-1}$ mm)	Rounded mean values ($x10^{-1}$ mm)	Corresponding penetrability indexes ($x10^{-1}$ mm)
		Series 1			Series 2					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
M_0	0	64	56	61	62	56	65	56-65	61	50-70
M_1	2	59	54	60	59	55	54	54-60	57	50-70
M_2	4	51	53	55	55	52	51	51-55	53	40-60
M_3	6	49	46	47	47	50	48	46-50	48	40-60
M_4	8	44	45	42	46	43	44	42-46	44	35-50
M_5	10	37	40	41	39	39	41	37-41	40	35-50
M_6	12	33	35	32	32	34	35	32-35	34	30-45
M_7	15	27	28	26	25	27	26	25-28	27	20-30
M_8	18	23	21	22	22	23	22	21-23	22	20-30
M_9	20	20	19	19	19	19	20	19-20	19	Out of standards

rized in Table 7.

The powder content was based on weight of waste plastic bags to weight of binder mix (50/70 bitumen + waste plastic bags powder). Analysis of these results showed that the incorporation of powder, from molten plastic bags, cooled and finely ground, at explored range contents, from 0 (M_0) to 20% (M_9), has a significant influence on penetration index of the resulting binder mixes. Indeed, in this Table 7, the obtained values (columns 3 to 8) were translated into ranges (column 9) and average values (column 10). In column (11) were displayed the five (05) classes to which belong different realized binder mixtures on the nine (09) bitumen classes as defined by the EN-1426 standards. Thus, the binder mixtures indexed M_0 to M_1 and M_2 to M_3, M_4 to M_5, M_6 and M_7 to M_8 correspond to bituminous binders of the respective five (05) following classes: 50/70, 40/60, 35/50, 30/45 and 20/30. The obtained value for binder mixes penetrability, at waste plastic bags powder content of 20%, leads to conclusion that, the corresponding bituminous binder M_9 exits from the known conventional grading roads bitumens. It rather enters the special grading bitumen of penetrability classes of 10/20 and 15/25 devoted to development of the high modulus asphalt concretes (HMAC).According to French Professional of Asphalt Group specialists, these two last grading bitumens rather provide answers to the caused problems by unexpected increase in heavy traffics. The recorded behavior for M_9 bituminous binder has practically indicated that, incorporation of more percentage of plastic bags powder, than 20%, in substitution for 50/70 graded bitumen in the course for designing bituminous binder's mixes, can be excluded from targeted blending. These results well corroborate the ones attained by Vasudevan et al. (2007) who worked on other kind plastics and 80/100 graded bitumen and recorded similar tendency but at more low plastic content (0 to 10%) than ours (0 to 20% wt/wt. binder mix). Similar results have been obtained by Jain et al. (2011) using the waste polymeric packaging materials. Conclusion was made that, all the designed binder mixes in current study, corresponding to five (05) on the known pure nine (09)

Table 8. Results of softening point measurements for tested binder mixes.

Testing ball (diameter) (mm)	Bituminous binders mix and corresponding softening points (°C)							
	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7
Ball 1 (9.35)	36	41	41	41	43	43	50	> 110
Ball 2 (9.35)	37	42	43	43	44	45	51	> 110
Mean-value (°C)	36.5	41.5	42	42	43.5	44	50.5	> 110

Table 9. Adhesivity odds values related to added powder percentage of melted plastic bags.

Bituminous mixtures	M_0	M_1	M_2	M_3	M_4	M_5
Adhesivity levels / odds	2-10	5-10	5-10	6-10	9-10	>10

grading bitumens for road coatings, can be substituted to the latters from their penetrability index viewpoint.

Results from softening point measurements of constituted binders

In analyzing the recorded values during effected measurements and reported in Table 8, it can be noted that, obtained value of softening point for the used 50/70 bitumen as control is relatively low (36-37°C) compared with that for true 50/70 graded bitumen. According to requirements of EN-1427 standards, softening point of grading 50/70 bitumen should normally lay between 46 and 54°C. Therefore, we thought that this observed difference (10-17°C) could be explained, either by improper quality or supply source, as well as the storage conditions of this 50/70 bituminous binder material prior to its admission in our laboratory. It is especially important to emphasize that, till now, the bitumens market is known to belonging to a rather protected professional sector, mainly with regards to the developing countries.

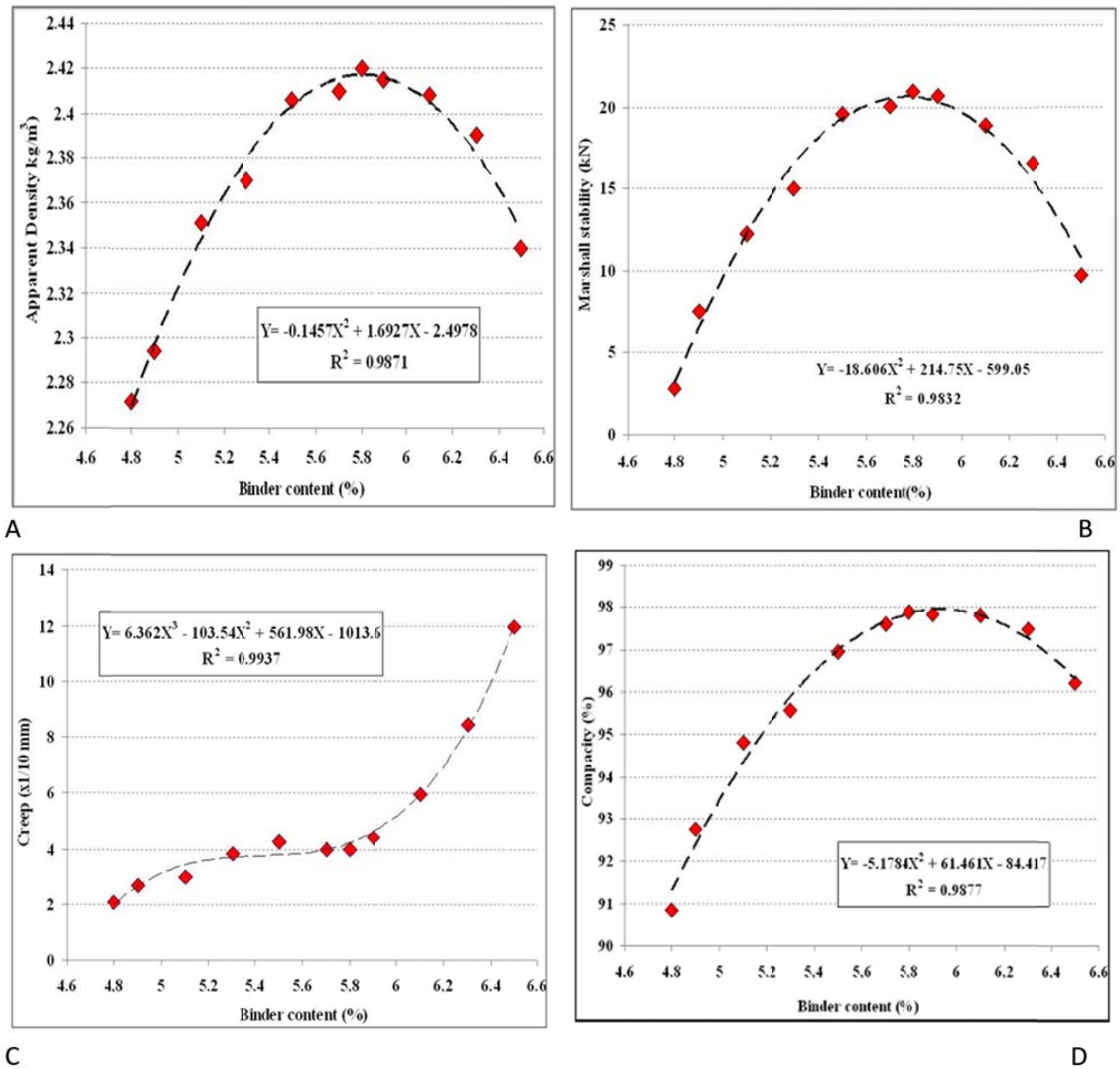
The used 50/70 witness/control bitumen in this study may thus not be exactly that truly normalized or accordingly, has already been probably aged to some extent in stock, at delivery time. However, it's found that, in global way, results from the carried out tests show that softening points of decoulant bituminous binders increases as the added percentage of waste plastic bags powder increases. These results well corroborate those published elsewhere (Jain et al., 2011; Garcia-Morales et al., 2006; Vasudevan et al., 2007, Sadeque and Patil, 2014) in which similar trends had been observed. The bituminous binder (M_7), containing 15% (by mass of plastic bags), has disclosed value of softening point exceeding admissible conventional limits (>94°C) using experimental water bath (80°C according to standards prescriptions). When making use of glycerol bath which allows to reach temperature of 110°C, the two testing balls then dropped in perforating the samples without softening the blended bitumen disc. The experiments series were then stopped to M_7 due to test temperature forthcoming that of glycerol's flash point which is around 160°C. This behavior clearly shows that the mix binder M_7 has very high consistency. Conclusion that can drawn at this step is that, incorporation of powder from the melted waste plastic bags to used 50/70 graded bitumen recovering binder mixes possessing softening point values reasonably closer to that for true 50/70 graded bitumen and subsequently having its performance from this point of view.

Results from adhesivity measurements for constituted binders

The values of recorded odds during adhesivity measurements were those summarized in Table 9. Analysis of these results led to conclusion that the incorporation of the melted waste plastic bags powder to conventional 50/70 graded bitumen affected, in positive way, ability of the derived binder mixtures to well adhere to aggregates: from 2-10 for M_0 (50/70 bitumen), through M_1, M_2 to 9-10 (M_4). This conclusion is evidenced by the fact that, there has been an increase in value of adhesivity odds with increasing the melted waste plastic bags powder content. The solution of S_2 concentration has spawned the beginning of stripping of the witness/control bitumen and with the S_9 solution, the obtained stripping was only partial.

All other bituminous mixtures have opposite a resistance to a pickling by solutions from the concentrated to highly concentrated, at point where no possibility exists to observe a stripping start prior to intervention of S_4 solution. The total stripping has therefore not been recorded, even with the most concentrated solution.

However, the realized pellet of bituminous binder and subjected to the conducted tests, after which the score 10 is reached for binder M_0, has seriously been degraded, while the pellets from mixtures M_4 and M_5 (>10) have experienced no detectable degradation following application of the same solution S_9. These results clearly show that the incorporation of the melted waste plastic bags



Figures 4. Evolutions of Apparent density (A), Marshall' stability (B), Creep (C) and Compacity (D) of the tested bituminous concretes as function of percentage of control 50/70 graded bitumen (M_0).

powder to conventional 50/70 graded bitumen M_0 permit augmenting adhesivity of decoulant binders and subsequently their quality in terms of binders extractible rates for the derived bituminous concretes.

Results from determination of bituminous binder optimal content

The results of various tests carried out for determination as well as, Marshall stability, apparent density, subsidence, creep, as that of voids rate (not shown), as function of the reference bituminous binder M_0 content (P %) in interval from 5.5 to 6.1%, are shown in Figure 4.

Analysis of these tests results allowed determining the optimal rate of bituminous binder dosage which was almost established to a value of 5.8%. Indeed, the deployed data on these figures clearly showed that this optimal value of 5.8% for M_0 binder content correspond those of maximal Marshall stability of 20.94 kN, maximal apparent density of 2.42 kg/m^3 and minimal creep of 3.997x1/10 mm. The latter is well located within the range of recommended values [2x1/10; 4x1/10mm] by Asphalt Institute for heavy traffics Roads Pavement (Bindu et al., 2010; Khan et al., 2009).

After apprehending the revealed behavior by each of

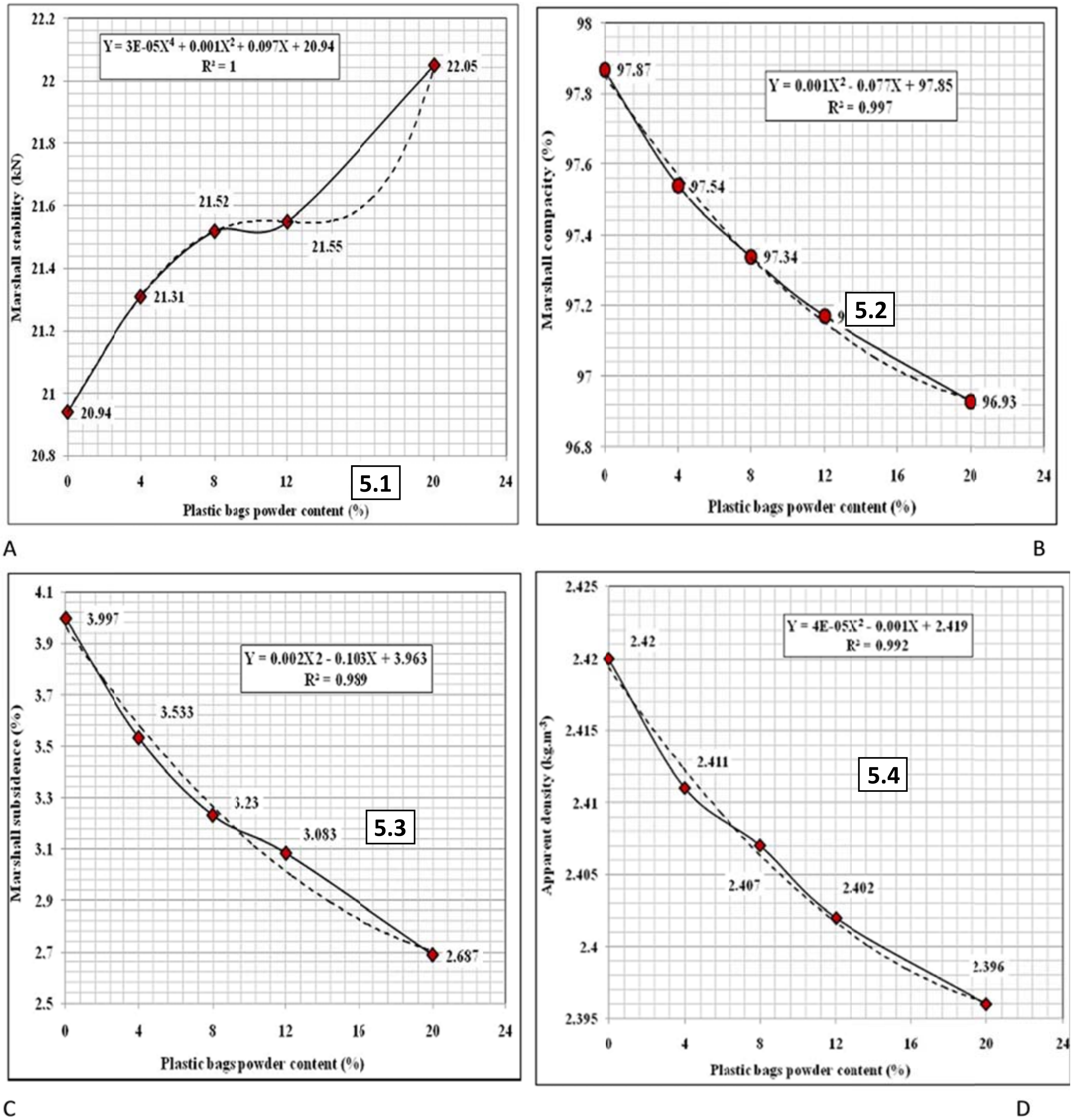


Figure 5. Effects of the added molten plastic bags powder contents on Marshall' stability (A), Subsidence (B), Compacity (C) and Apparent density (D) of doped bituminous concretes (solid lines = experimental data curves; dash lines = trend curves).

these characteristic parameters in case of chosen pure 50/70 graded bitumen (M_0) as control, the tests were then realized using the mixed binders made of incorporated powder from molten waste plastic bags into the grading 50/70 bitumen, as well as their derived bituminous concretes (the final Asphalt materials for road coatings/-pavements). The results of these done experimental measurements were those embedded in Figure 5.

Analysis of results of Marshall's tests on bituminous - plastic bags powder concretes

Remember that the tested powder contents for the melted waste plastic bags in this series were 4, 8, 12 and 20%. The powder content was based on the weight of melted waste plastic bags to the weight of mix binder (50/70 graded bitumen + waste plastic bags powder).

They correspond to the plastic bags powder incorporated bituminous binders previously identified respectively as M_2, M_4, M_6 and M_9. In view of performances comparison, obtained results were faced against those from pure bitumen binder (M_0).

Effects of plastic bags powder content on bituminous concrete bulk density

In Figure 5a shows the results for evolution of the bulk density of bituminous concrete made of bitumen doped in plastic bags powder. It clearly shows that the bulk density of the bituminous concrete decreases as the powder content of introduced molten waste plastic bags into 50/70 graded bitumen increases from 0 to 20% although variation of the density appear relatively low: less than 1% (exactly 0.99%) against a theoretical variation, based on the used bitumen as a control (M_0) of 0.58%. These results well corroborate the observed trend elsewhere in working on the mixture of cement mortar and plastic composite (Yazoghli-Marzouk et al., 2005). The polynomial function that adequately fits the data from the evolution of apparent density (Y) versus the molten plastic bags powder content (X) may be represented by the tendency equation expressed as:

$$Y = 100.9 \cdot X^4 - 39.84 \cdot X^3 + 5.213 \cdot X^2 - 0.376 \cdot X + 2.42 \quad (5)$$

With a regression coefficient value of: $R^2 = 1$.

Effects of plastic bags powder content on Marshall' stability of bituminous concretes

The recorded results, from evolution study on the Marshall stability of blended Asphalt concretes using powder of waste plastic bags, are shown in Figure 5b. These exposed data allow concluding that Marshall' stability of this developed bituminous concrete increases with rising of the molten plastic bags powder content. Similar results have been recorded using Styrene Butadiene Styrene (SBS) polymer modified bituminous mixes on fatigue performance of roads (Gupta and Veeraragavan (2009) and the waste plastic polymers (Sadeque and Patil, 2014).

Indeed, it is noteworthy that the rate of change of the Marshall stability is about 5.03% against a theoretical rate of change of 9.89% corresponding to percentage content values of powder incorporation of melted plastic bags from 0 to 20%. The polynomial function that adequately fits the data from behavior of the Marshall stability (Y) of studied materials versus variation of added powder content from melted plastic bags (X), can be represented by the obtained trend equation:

$$Y = 390.6 \cdot X^3 - 120.9 \cdot X^2 + 14.14 \cdot X + 20.93 \quad (6)$$

with a regression coefficient of almost equal to: $R^2=0.997$.

This is a polynomial function of degree 3 admitting an inflection point around value of waste plastic bags powder content X = 10%.

Effects of plastic bags powder content on bituminous concrete creep

The recorded results, during realized measurements from the Marshall creep's assays on built bituminous concrete specimens from the obtained powder by grinding of the plastic bags wastes melted, bitumen 50/70 and aggregates, are presented in Figure 5. The evolution of these data clearly shows that the values of bituminous concrete creep decreases significantly when increasing the molten plastic bags powder content. Indeed, the rate of change of creep, by calculating the difference between the extreme values multiplied by one hundred divided by that of the control gives about 32.77% against theoretical rate variation of 32.82% for a contents' range of plastic bags powder from 0 to 20%. Both these obtained two rates thus are almost the same order of magnitude: the difference only about 5%.

The polynomial function that adequately fits the data from the creep evolution (Y) versus the molten plastic bags powder content (X), may be represented by the trend equation expressed as:

$$Y = -242.7 \cdot X^3 + 91.94 \cdot X^2 - 15.24 \cdot X + 4 \quad (7)$$

with a regression coefficient equal to $R^2=0.999$. It's also a polynomial function of degree 3 admitting an inflection point around the value of plastic bags powder content of X=10%.

Analysis of results of Duriez tests on doped bituminous concrete using plastic bags

Like the achieved measurements in Marshall tests, the done Duriez tests use identical bituminous binders made of powder from the melted waste plastic bags incorporated into aggregates at contents of 4, 8, 12 and 20% (blended binder weight) corresponding to the indexed respective binders M_2, M_4, M_6 and M_9. The control bituminous concrete (0%) remains unchanged: that from the 50/70 graded bitumen (M_0).

However, it must be underlined that additional experiences have also been performed using specific binder consisting of the pure molten plastic bags powder only, being four (04) mixes, the control (0% or M_0), plus additional pure plastic samples.

Results of Duriez stability measurements

The results for evolution study of the three (03) tested versions of Duriez stability are those gathered in Figure 6. Note that the Duriez stability three versions consist on determination of respective resistances of the designed bituminous concretes: first, after 1-day storage at tempe-

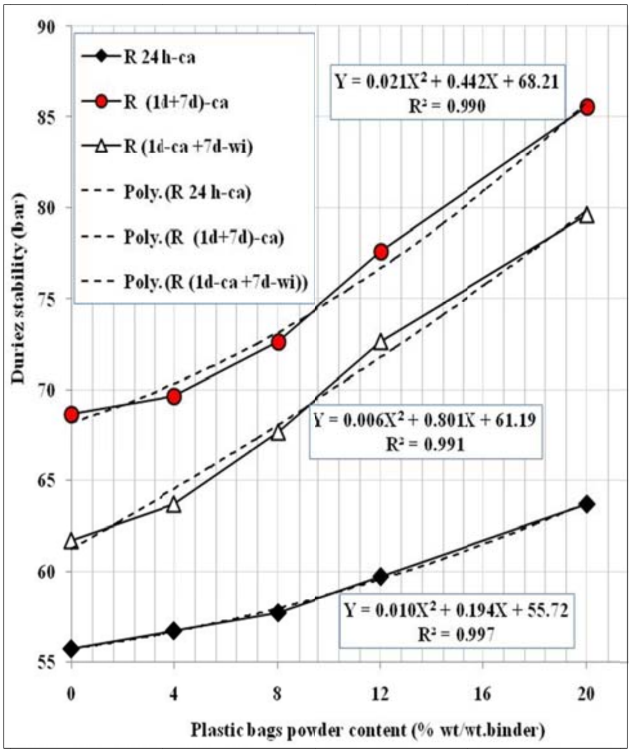


Figure 6. Evolution of Duriez stability of built bituminous concretes versus their molten plastic bags contents: R24h-c.a: on the controlled air (c.a) for 24 h; R(1d+7d)-c.a: on controlled air (c.a) for 8 days; R(1d-c.a+7d-w.i): 1-day on controlled air + 7-days water immersed (w.i) at 18°C.

rature of 18°C on the open-air (called as controlled air); second, after 8-days storage at temperature of 18°C on the open-air; third, 1-day storage at controlled air completed with size-days water immersing at temperature of 18°C.

Duriez stability of bituminous concretes after 1-day of controlled air storage

It can be observed that the Duriez stability of the bituminous concrete samples, stored 24 hon the air, increases with augmentation of their plastic bags powder content (Figure 6). It should be noted that the rate of change of Duriez stability is around 14.28% for incorporation range of plastic bags powder contents from 0 to 20%. The polynomial function that adequately fits the data from the behavior of bituminous concrete resulting data from Duriez stability study after 24 hours air storage

(Y) versus the melted waste plastic bags powder content (X), may be expressed by following trend equation:

$$Y = 0.0103 \cdot X^2 + 0.1949 \cdot X + 55.721 \quad (8)$$

with a regression coefficient value of almost equal to: R^2=0.998.

It is a parabolic branch function with concavity facing upwardly which minimal value being that of the obtained bituminous concretes from reference bitumen M_0 freed of plastic bags powder.

Duriez stability of bituminous concretes after 8-days of controlled air storage

At 8-days aged, following preservation on the air at temperature of 18°C, the Duriez stability of bituminous concrete samples increases with rising of the molten plastic bags powder content (Figure 6). The rate of change of Duriez stability values is about 24.64% for incorporation range of plastic bags contents from 0 to 20%. The polynomial function that adequately fits the data from behavior of the studied Duriez stability on the bituminous concretes after 08 days preservation on the air (Y), versus the melted plastic bags powder content (X), may be expressed by the trend equation:

$$Y = 0.0219 \cdot X^2 + 0.4429 \cdot X + 68.214 \quad (9)$$

with a regression coefficient value of almost equal to: R^2=0.990. Here, we also find a satellite branch concavity facing upwards, the minimum value being that of bituminous concrete from control 50/70 graded bitumen (M_0) freed of powder from melted waste plastic bags.

Duriez stability at 1-day on controlled air following by 7-days water immersion

At 8-days aged, with storage for 24 h on the air at a temperature of 18°C completed with 7 days of water immersion at the same temperature, the bituminous concrete stability is experiencing growth with increasing the powder content of molten plastic bags (Figure 6). The rate of variation of Duriez stability is about 29.04 % for incorporated content values of plastic bags powder going from 0 to 20%.

The polynomial function that adequately fits the data from the behavior of Duriez stability of bituminous concretes on the air at 01-day and 7-days water immersed (Y), versus the powder content of molten plastic bags (X), can be described by the trend equation:

$$Y = 0.0066 \cdot X^2 + 0.8014 \cdot X + 61.195 \quad (10)$$

With a coefficient of regression equal to: R^2=0.991.

Here again, a parabolic branch function with concavity facing upwards was obtained, the lowest value being that for bituminous concrete from pure 50/70 graded bitumen binder (M_0) freed of powder from the melted waste plastic bags. Ultimately, these results clearly lead concluding that, all forms of the determined Duriez stability for the designed bituminous concretes displayed growth as the waste plastic bags powder content is experiencing an

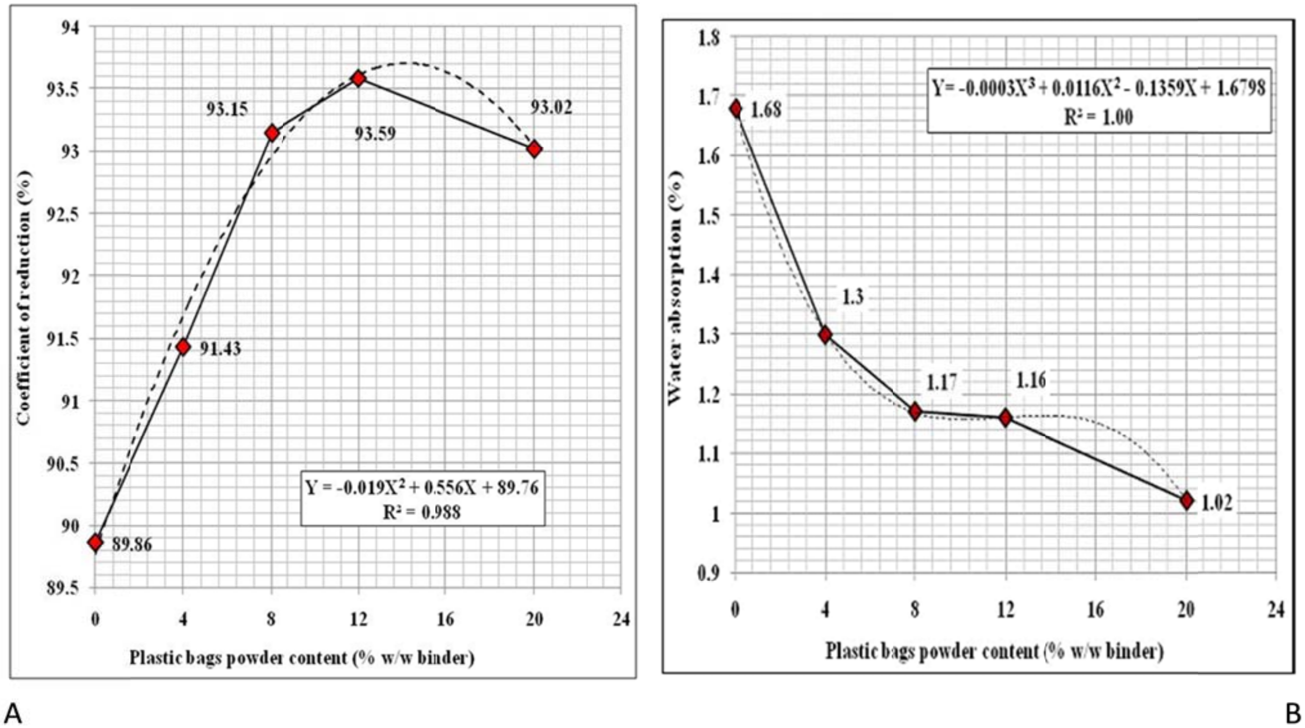


Figure 7. Duriez testing results: respective behaviors for water absorption rate at (1-day in controlled air + 7-days water immersed at 18 °C) (A) and reduction coefficient (B) of bituminous concretes versus plastic bags powder content.

increase in the studied range values of 0 to 20 % (wt/wt mix binder). In analyzing these data, at global level, one observes that, more bituminous concretes matured, from 1 to 8 days, either on the controlled air or in water immersion state, more their Duriez stability increases. At identical plastic bags powder contents, values of the provided Duriez stability by the immersed specimens in water for seven days, after spending 24 h on the controlled air, are much lower than those for not water immersed. Differences in recorded values for purpose ranged from 5.97 to 6.97 bars corresponding to an increase in resistance of 7.5 to 11.30% with reference to those from water immersed specimens.

Results for water absorption rate of the developed bituminous concretes

From the 7-days water immersion, following the 24-h aged on controlled air, as prescribed by standards procedure, the recorded experimental results showed a decrease of rate for water absorption of the tested specimens from bituminous concretes as percentage of powder from melted waste plastic bags increases (Figure 7a).

Recommended rate values of water absorption for aircraft runways and highways are less than 4% (Duriez and Arrambide, 1959). The chosen 50/70 graded bitumen and used alone as witness/control main bituminous binder, already met this requirement with a water absorption rate of 1.68%. The incorporation of a water repellent into bituminous concrete, as case of powder from the melted waste plastic bags, has permitted obtaining a significant improvement in terms of reduction of the water absorption rate. Definitely, these experimental results have clearly shown that incorporation of plastic bags powder improves the water resistance by reducing its water absorption rate to 1.16% at 12% plastic bags powder content (wt/wt mix basis). At 20% plastic bags powder content, the water absorption rate of these doped bituminous concretes falls to 1.02%, corresponding to a reduction ratio of about 39.3% with reference to value for non doped 50/70 graded bitumen (1.68%).

This significant reduction of water absorption rate has been attributed to incorporated plastic bags material which has therefore permit a partial sealing of the porous structure of bituminous concretes by generating some excrescences through the aggregates boundaries, favoring the plugging of borrowable passages by water between grains of aggregates. This must constitute a qualitative good performance if the coating of roads has efficiently been realized with a firmed application of the suggested new binders.

Results from coefficient of reduction measurements for bituminous binder mixes

The test results show that the control 50/70 graded bitumen alone has already achieved a reduction coefficient of 89% (Figure 7a) indicating that the quality of this chosen control bituminous binder is not so bad from this point of view. Moreover, the shown data in this figure clearly indicate that the incorporation of powder from the melted waste plastic bags has contributed to some performance improvement of the explored characteristics for bituminous concretes: from 91 to 93.5 %. Indeed, the reduction coefficient, defined as 100 times the established ratio between resistance (R') in compression after storage on the air at 18°C for 1 day completed with 7-days water immersion and resistance (R) in compression for 8-days maintain at 18 °C at open-air, is an important parameter that reflecting the influence of water soaking the bituminous concretes on their resistance. Commonly prescribed in specifications in form of R'/R (> 0.70), it's specifically recommended R'/R values greater than 0.80 (R'/R > 0.80) for aircraft runways and highways, and relatively lower values of R'/R > 0.65 for secondary roads.

On light of previous recommendations, the derived bituminous concretes, from the incorporation of powder from the melted waste plastic bags, exhibited significantly higher values of R'/R as shown in Figure 7 (Right side): from 0.899 to 0.936. It then follows quite interesting and promising experimental results that must encourage the professionals in site to adopt such the designed bituminous binders for the road coatings or pavements.

The polynomial that adequately fits the data with respect to displayed behavior by the bituminous concretes' reduction coefficient (Y), as the incorporated powder content (X) of the melted waste plastic bags varies, is a polynomial function of second degree (Figure 7):

$$Y = -0.0197 \cdot X^2 + 0.5568 \cdot X + 89.766 \qquad (11)$$

with a regression coefficient value of: R^2=0.9888.

Its first derivation leads to the following equation:

$$dY / dX = -0.0394 \cdot X + 0.5568 \qquad (12)$$

It vanishes and changes sign around maximal value of plastic bags powder content of X=14%, corresponding to reduction coefficient value of Y=93.7%. In fact, it can be remarked that the value of (dY/dX) for X=14.13197969 is 2.10^{-10} whilst for X=14.13197970, the taken value by (dY/dX) is -2.10^{-10}.

In a quest of higher performance, where the reduction coefficient is sought a priori, the decline of trend curve is questionable. However, let just closely observing the values of Duriez stability that lead to calculation of the reduction coefficient. Already, from about 9.5 % incorporated powder from the melted waste plastic bags (Figure 6), the acquired resistance after water immersion (R') is 69 bar and begins to exceed that for Asphalt concretes made of 50/70 graded bitumen (M_0) without any water immersion (R=68.67 bar). At plastic bags content of X=11%, R=70 bar and at X=12%, R=72.65 bar. Therefore, it cannot be there a counter-performance at all. It must be understood that the new doped binder using plastic bags powder escapes the defined frame of established laws for the reference 50/70 bitumen. This revealed behavior, by the doped bituminous concretes using powder from the melted waste plastic bags, offers greater resistance on Duriez testing and more satisfactory operation than that from bituminous concrete prepared on basis of the reference 50/70 graded bitumen only, in the identified range values of waste plastic bags content: from 9.5 to 14%. The experimental results show that the range of high values of reduction coefficient, from 93.15% to maximum of 93.7%, corresponding to those of powder contents, from 8% to maximum of 14%, is advantageous for processes of road coatings. Further investigations are therefore needed with the purpose of well marking the required range concentrations and subsequently for better refining these achieved results, if the proposed orientation for recycling waste plastic bags (in quality of dope for 50/70 graded bitumen), should eventually integrate infrastructural construction habit, particularly in building of roads in Benin country.

Analysis of results from subsidence rate measurements

The subsidence, also called creep, measures the height deformation in breaking of a test specimen. For bituminous concretes, the limit of good performance for creep flow, one of these Asphalt concretes quality parameters, is 5% (Duriez and Arrambide, 1959; BCEOM-CEBTP, 1975). Excess creep flow is the expression of the lack of stability resulting in the risk of deforming under the traffic effects. The bituminous concrete, based on pure 50/70 graded bitumen binder, provided a determined value for subsidence rate of 5.95±0.07% (Figure 5c) higher than this prescribed limit of 5%. It is a true indication that this classically used 50/70 graded bitumen in Benin presents an obvious risk of deformation for the coated or paved roads under traffic. The experimental results, from doping of the same 50/70 bitumen, by incorporating the powder of the melted waste plastic bags, have shown significant reduction of the subsidence rate for these prepared composites. This diminution should thus allow avoiding the risk of high values of subsidence rate. Undeniably, the results showed that, for a content of 8 % (by weight) of incorporated plastic bags powder, the rate of subsidence of bituminous concrete has set to 4.47 %. Better, in grading plastic bags to 20%, the rate of subsidence decreased to 3.35% (Figure 5.3).

These results corroborate obtained similar trends of deformation reduction elsewhere (Jain et al., 2011; Prasad et al., 2009). From the shape of this results curve,

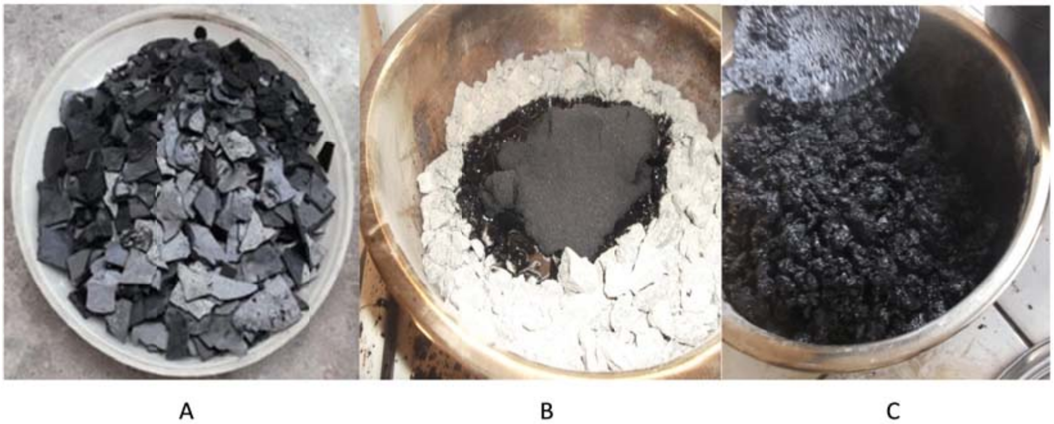


Figure 8. The plastic bags powder used alone as binder for concretes: platelets of the melted waste plastic bags (A), melting of powder on aggregates (B) and decoulant concrete ready to be molded (C).

one can deduce that the deformation of the Asphalt concretes under applied stress decreases with rising of the powder content of the melted waste plastic bags. A polynomial function that adequately fits the data from the developed behavior, by the bituminous concrete subsidence (Y) versus change in powder content (X) of the incorporated plastic bags, is also of second order expressed as:

$$Y = 0.0048 \cdot X^2 - 0.2244 \cdot X + 5.9202 \qquad (13)$$

With a value of regression coefficient of R^2=0.9982.

This is an interesting proof of quality improvement for bituminous concretes which can stimulate the adoption of devised process consisting of incorporation of the powder from the melted waste plastic bags as binder for coating of roads. It should be awful, mainly for the well-known case of Benin Republic, where the built roads frequently plagued to slumps/subsidence which rather proved disastrous for the durability of this infrastructural construction.

Study results on concretes using powder from pure plastic bags as binder

In order to potentially encourage massive usage of plastic bags powder, the latter was tested alone as pure binder (100%) in manufacture of what we call “non-bituminous concretes". To do this, the same formulation as that for pure reference 50/70 graded bitumen (M_0), the aggregates composition and even the value of modulus of richness in binder of 5.8%, was adopted. The photographs of Figure 8 show, platelets of the melted waste plastic bags (a), while at the middle, the powder melts on the aggregates (b), and on right side, the bound concrete using powder from the melted waste plastic bags" after mixing (c). The recorded results from the various Marshall and Duriez testing, on specimens from bound concretes using the pure powder of melted waste plastic bags, instead of grading 50/70 bitumen, are gathered in Tables 10 and 11 respectively. Analysis and comments of these collected data are carried out in the paragraphs to follow.

Results from Marshall’ stability test for concretes from pure melted waste plastic bags

From these shown data in Table 10, which is a typical template for Marshall testing results, it can be concluded that:

The Marshall stability, for concretes made uniquely of molten plastic bags powder, is 1.80 times the stability of bituminous concrete from 50/70 graded bitumen and only 3.14 times the conventionally prescribed value of 12kN by specifications; The Duriez stability in controlled air at 8-days aged, for concretes made of plastic bags powder, is 1.87 times the stability of bituminous concrete from 50/70 graded bitumen and only 2.57 times the prescribed value of 50 bar by specifications; The Duriez stability value for bituminous concretes made of pure plastic bags powder only, preserved for 1-day on the controlled air and water immersed for 7 days, is 1.53 times the recorded stability value for Asphalt concretes from 50/70 graded bitumen and only 2.70 times the prescribed value of 35 bar by specifications. It follows, from stability of bituminous concrete viewpoint, that the powder of melted waste plastic bags, used alone as a binder, can give to bituminous concrete more efficient characteristics than that provided by 50/70 graded bitumen alone. It may be noted that stability determination tests, from Marshall and Duriez methods, are both complementary and cover all the overall quality of the studied composite concretes. They only differ in two important characteristics: operating temperature of 60°C for Marshall tests against 18°C for those of Duriez in the one hand, and stress

Table 10. Results from Marshall tests on concretes using pure plastic bags powder as binder.

Parameter	Value
Aggregates' true volumetric density	2.69 (g/cm^3)
Samples apparent hydrostatic density	2.354 (g/cm^3)
True density of mixture	2.472 (g/cm^3)
Bitumen volume rate	12.49 (%)
Aggregates volume rate	82.73(%)
Residual voids volume rate	4.79 (%)
Compacity rate	95.21 (%)
Aggregates volumetric density	2.225 (g/cm^3)
Rate of aggregates voids	17.29 (%)
Rate of voids filled	72.37(%)
Creep flow	1.930 (x1/10 mm)
Marshall Stability	37.74 (kN)

Marshall Tests Results foil's template; Bitumen: 0%; Plastic bags powder: 100%; Binder rate/Aggregates: 5.8%.

Table 11. Results of Duriez tests on composite concretes bound with pure plastic bags powder.

Parameter	Value
Resistance in simple compression (1-day on the open-air at 18 °C)	94.55 (bar)
Resistance in simple compression (8-days on the air at 18 °C)	128.38 (bar)
Resistance in simple compression (1-day controlled air + 7-days water immersed at 18 °C)	94.55 (bar)
Water absorption rate (1-day/air + 7-days water immersed at 18 °C)	0.76 (%)
Coefficient of reduction	73.64 (%)
Subsidence	1.16 (-)

Duriez Tests Results foil's template; Bitumen: 0%; Plastic bags powder: pure or 100%; Binder rate/Aggregates: 5.8%.

application mode to specimen, on the other hand: along specimen generatrix in Marshall's tests against axial direction in Duriez ones.

Water absorption rate of concrete bound using pure powder from plastic bags

Concrete made of melted plastic bags powder and stored for 1-day on the controlled air and 7-days submerged in water absorbs 2.21 times less water than bituminous concrete from pure 50/70 graded bitumen and 5.26 times less than the prescribed limit on site of 4% by specifications.

Marshall's creep of concrete bound using pure powder from waste plastic bags

Marshall's creep flow is prescribed to take value between 2 and 4.10^{-1} mm. It is known that an excess of creep flow is especially harmful to the floor. While the bituminous concrete from pure 50/70 graded bitumen accused creep's value at the upper limit of the acceptable (3.997×10^{-1}mm), the creep value for concrete made of plastic bags powder is located at the lower limit (1.93×10^{-1} mm). These results allow us to affirmatively conclude that the designed concrete using pure plastic bags powder subsides two times lower than concrete made of 50/70 graded bitumen alone.

Duriez subsidence of concrete bound using pure powder from waste plastic bags

Duriez subsidence is always prescribed and must remain below or at most equal to 5%. Concrete made of melted powder from waste plastic bags collapses 4.31 times less than this requirement and 5.13 times less than the bituminous concrete from pure 50/70 graded bitumen basis (Table 11).

Ultimately, the data, collected at the end of these expeririments series, point out that the melted plastic bags powder, used alone, can act as a good binder for making a similar kind of bituminous concrete even though it does not have the characteristics of specific graded bitumen. Indeed, the obtained values, for some quality characteristics, such as compactness, are relatively low: 95.21 % against provided rate of 96 % to 98 % by 50/70 graded bitumen.

Despite the noticeable reduction of density for this plastic bags composite material (2.35 t/m^3) comparatively to that for composite material from 50/70 bitumen (2.42 t/m^3), it is estimated that all of the obtained other results resolutely contribute to strengthen the relevance of idea behind the massive use of waste plastic bags, as dope in the formulation and implementation of new bituminous concretes or as "pure" binder for a "similar" concretes in the context of roads construction.

However, further studies are needed to improve some of performance parameters among others quite attractive for the new formulated concretes. Prospects are promising and many fields of research are to be achieved for.

Quality validation for doped bituminous concretes using melted powder plastic bags

According to experienced data, the standard penetrability S_P (x1/10 mm) of a bituminous binder at temperature of 25°C and the Duriez stability of resulting bituminous concrete at 8-days aged on the controlled air R (bar) are linked by correlation of the following form (Duriez and Arrambide,1959):

$$\log R + (2/3)\log S_P = \gamma = C^{ste} \tag{14}$$

More the γ-value approaches γ≈3 (by lower values), higher is quality of the bituminous concrete. A γ-value of 2.875 indicates a middle quality bituminous concrete and a γ-value of 2.7 corresponds to frontier between the bituminous concrete and bitumen coated dense products.

In case of the proposed new binder mixes in this study, if one considers average value of recorded penetrability from the used reference 50/70 graded bitumen alone (pure that is without any added dope), being S_P=61x1/10 mm and its Duriez stability value at 8-days aged on the controlled air: R=68.67 bar, one obtains γ=3.02 from relation (14).

It is a closed value to γ≈3 which allows confirming that the developed bituminous concretes belong to the ones categorized as of very good quality.

Elsewhere, the 50/70 graded bitumen used as main bituminous binder has displayed softening point value of T=36.5 °C and the derived bituminous concretes reached resistance, at 8-days conservation on the controlled air, of R=68.67 bar. These known values of T and R lead to determination of ratio 1/λ, hence λ another quality index that also permits categorizing the bituminous concretes and is calculated from the following relation:

$$1/\lambda = (T)^{2.64}/R \tag{15}$$

In replacing T and R by their respective values, one arrives to 1/λ:

$$1/\lambda = (36.5)^{2.64}/(68.67) = 194.$$

This value of λ=1/194 is largely higher than limit of λ=1/500 marking the good quality bituminous concretes compared to those designated as middle-quality ones having λ-value of 1/750 on one hand and to concretes situated at frontier between the said bituminous and bitumen dense coated products possessing λ-value of 1/1000, on the other.

The thermal susceptibility (h) of grading bitumen is another important quality indicator in terms of so called “maintain and durability” for a bituminous concrete, as does adhesivity for a bituminous binder. It’s linked to usually employed Penetration Index (IP) determined by following equation (Naskara and Chakia, 2010; Jeuffroy, 1978):

$$h = [\log 800 - \log P_{25}]/[T_{BA} - 25] = (1/50)\cdot[20 - IP]/[10 + IP] \tag{16}$$

With T_{BA} as the Ball and Ring temperature in measurements of binder (bitumen) penetrability.

The value of penetrability index for any grading bitumen at temperature of 25°C (P_{25}) is approximately equal to 800. More IP-value is high, minus this bitumen’s thermally susceptible. Current values of IP are comprised between -3 and +8 while simple distillation bitumens have negative index values or lesser than 1 and blowing bitumens, feebly or less heat susceptible, disclosed positive indexes. Application of relation (16) and those established limits let concluding that:

1) The thermal susceptibility of pure 50/70 graded bitumen is higher (IP=-5). This might explain some of these frequently recorded defaults, provoked by the combined effects of traffic and operating temperature on the Beninese coated roads, using this kind of graded bitumen. From then, it must be adequate for hot climate countries, like Benin Republic and those of sub-region, where the problem to solve concerns temperature always higher (27 to 45°C) than the chosen reference of 25°C in temperate climate countries, to search for lower convenient thermal susceptibility in displacing IP-values towards zero, seeing positive values.
2) The doped bitumens, using from 2% to 12% (wt/wt.mix) of powder from the melted waste plastic bags, enter the classical susceptibility values laying in IP-interval going from IP=-3 to IP=-2. The incorporation of melted powder of waste plastic bags positively acts in

that, it permits displacing the penetrability index from that of pure 50/70 graded bitumen (IP=-5) towards IP-interval of [-3, -2] in a subsequent increase tendency, even though, the resulting values are negative but well located the corresponding binders into those possessing IP-values in interval of [-3, +8] previously located above.

3) At 15% powder content (wt/wt.mix) of melted waste plastic bags, if glycerol reached temperature of 110°C was considered as softening point, the derived value for thermal susceptibility index might be of 6. In this case, corresponding doped bitumen mix would be the best, compared with others, in the operating conditions of the coated roads of Benin.

Conclusions

The goal in this investigation is to identify the relevant and promising means to recycle the waste plastic bags that offer spectacular nuisance in all cities and villages of Benin Republic and of the sub-region. The construction processes were identified as being the potential reducers and then, in significant manner, of the huge amount of harmful waste plastic bags. To do this, the chosen, developed and analyzed process, in this article, was the one oriented towards utilization of the waste plastic bags (thermally melted, cooled and reduced into powder), as a dope for bituminous binders in roads construction. The study identified and analyzed the essential characteristics of the developed bituminous binders by partially or completely substituting the obtained melted from heated waste plastic bags, finely ground in powder (0.160 mm mean diameter) to the 50/70 graded bitumen. At the end of testing series based on ten (10) variants of doped bitumens mixes with powder from the melted waste plastic bags at respective percentages of 0, 2, 4, 6, 8, 10, 12, 15, 18 and 20% (wt/wt.mix), the reached results allowed concluding that the realized substitution has had the effects of progressively declassifying the bituminous binders towards the hardest grading bitumens: from 50/70, transiting by 40/60, 35/50, 30/45 to even 20/30. These different bituminous binder mixes, obtained from the incorporation of powder from the melted waste plastic bags have developed a better adhesivity to aggregates in corresponding built bituminous concretes. They showed increasing values of Duriez stability of 14.28 - 29.04 % with respect to the used main binder as control consisting of 50/70 graded bitumen alone, when increasing the rate of waste plastic bags powder. It resulted in a weak decreasing trend for the bituminous concretes bulk density: -0.99%.

The decrease tendency was relatively significant, as predicted from creep's measurement which has dropped from 3.997 to 2.687% (being a reduction of 32.77%), leading then to suitable value for a good coating. Finally, the results of this study revealed also that, the powder from the melted waste plastic bags, although it does not have identical characteristics to conventional 50/70 graded bitumen, is able, in itself used alone, to act as a binder of good quality in the manufacture of similar concretes as that from studied 50/70 bitumen. Further studies are therefore needed in intend for finely improving some features of its binder characteristics. However, results of the performed tests on the built bituminous concrete specimens from pure powder of melted waste plastic bags showed that, Marshall' stability on the one hand, and Duriez stability at 8 days on controlled air, from each other, are significantly higher, by approximately 80 and 87% respectively, than that provided by 50/70 graded bitumen. The results from thermal susceptibility study let clearly knowing the consequence of incorporating powder from melted waste plastic bags, improving bituminous binder's penetrability index intimately linked with the consistency (seeing adhesivity) and then durability of bituminous concretes used in road coatings or pavements.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Afroz Sultana SK, Prasad KSB (2012). Utilization of waste plastics as a strength modifier in surface course of flexible and rigid pavements. Int. J. Eng. Res. Appl. 2*(*4): 1185-1191.

Al-Hadidy AI, Tan YQ (2009). Effect of polyethylene on life of flexible pavements. Journal of Construction and Building Materials, 23 (3):1456-1464.

BCEOM-CEBTP (1975). Manuel sur les routes dans les zones tropicales et désertiques. Tome 2. Etudes et Construction. Editions du Ministère Français de la Coopération, Paris. (BCEOM: Bureau Central d'Études pour les Équipements d'Outre Mer - CEBTP: Centre Expérimental de recherche et d'Etudes du Bâtiment et des Travaux Publics). 484p.

Behjat Y, Cheng J, Polak M, Penlidis A (2014). Effect of Molecular Structure on the Short-Term and Long-Term Mechanical Behavior of High-Density Polyethylene. J. Mater. Civ. Eng. 26(5): 795-802.

Bindu C, Beena KS (2010). Waste plastics as a stabilizing additive in Stone Mastic Asphalt. Int. J. Eng. Technol. 2(6):379-387.

Coquand R(1978).Routes. Livre 2. Editions Eyrolles, Paris (France); p.337.

Doko VK (2013). Formulation et étude comparative des propriétés physiques, mécaniques et thermiques de composites à matrice cimentaire renforcée par des biomasses végétales : cas des fibres de Borassus Aethiopium Mart et des balles de riz. Thèse de Doctorat Unique, Université d'Abomey-Calavi. 196p.

Duriez M, Arrambide J (1959). Liants routiers et enrobés. Editions Dunod et Editions du Moniteur des Travaux Publics, Paris. 553p.

Garcia-Morales M, Partal P, Navarro FJ, Gallegos C (2006). Effect of waste polymer addition on the Rheology of modified bitumen. Fuel, 85(7-8):936-943.

Gbèdo AV (2009). Problématique de la valorisation des déchets plastiques à Cotonou. Thèse de Doctorat Université d'Abomey-Calavi, Faculté des Lettres Arts et Sciences Humaines. 237p.

Ghernouti Y, Rabehide B (2009). Récupération et Valorisation des déchets de sacs en plastique dans le domaine de construction. In 'Proceedings of 1st International Conference on Sustainable Built Environment Infrastructures in Developing Countries'. Edition ENSET Oran (Algeria), 12-14 October: 93-100.

Gupta S, Veeraragavan A (2009). Fatigue behavior of Polymer Modified Bituminous Concrete Mixtures. J. Indian Roads Congress. Paper

568:55-64.
Huang Y, Bird RN, Heidrich O (2007). A review of the use of recycled solid waste materials in bituminous pavements. School of Civil Engineering and Geo Sciences April 2007. Resour. Conserv. Recycling (Elsevier) 52: 58-73.
IRC (2001). Guidelines for The Design of Flexible Pavements. Indian Roads Congress Publishers. Second Revision, July 2001, New Delhi 110011, p.77.
Jain PK, Kumar S, Sengupta JB (2011). Mitigation of rutting in bituminous roads by use of waste polymeric packaging materials. Indian J. Eng. Mater. Sci. 18(3): 233-238.
Jeuffroy G (1978). Conception et construction des chaussées. Tome 2. Les matériaux, les matériels, les techniques d'exécution des travaux. Editions Eyrolles, Paris. 431p.
Kalantar ZN, Mahrez A, Karim MR (2010). Properties Of Bituminous Binder Modified With Waste Polyethylene Terephthalate. Proceedings of Malaysian Universities Transportation Research Forum. December, 18-04-13 GTR 236 30.
Kapil S, Punjabi KK (2013). Improving the Performance of Bituminous Concrete Mix by Waste Plastic. Int. J. Eng. Res. Appl. 3(5): 863-868.
Khan TA, Sharma SDK, Sharma BM (2009). Performance evaluation of waste plastic/polymer modified bituminous concrete mixes. J. Sci. Ind. Res. 68:975-979.
Lawson V, Liady N, Boglo G (2008). Valorisation des déchets solides ménagers (DSM) au Benin: atouts et limites. Rapport d'étude DCAM-BETHESDA. Cotonou. 63p.
MEHU (2002). Etude de faisabilité pour la valorisation des déchets plastiques au Bénin. Ministère de l'Environnement, de l'Habitat et de l'Urbanisme du Bénin. Rapport, Cotonou.
Moatasim A, Cheng PF, Al-Hadidy A (2011). Laboratory evaluation of HMA with high density polyethylene as a modifier. Constr. Build. Mater. 25(5):2764-2770.
Naskara M, Chakia TK, Reddy KS (2010). Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend. Thermochim. Acta 128-134.
Panda M, Mazumdar M (1999). Engineering Properties Of Eva Modified Bitumen Binder For Paving Mixes. J. Mater. Civ. Eng. 11(2):131-137.
Prasad DSV, Prasada-Raju GVR, Kumar A (2009). Utilization of Industrial Waste inn Flexible Pavement Construction. EJGE J. 13(D):1-12.
Punith VS, Veeraragavan A (2007). Behavior of Asphalt Concrete Mixtures with Reclaimed Polyethylene as Additive. J. Mater. Civ. Eng. 19(6):500-507.
RNCR (2011). Etude sur la gestion des déchets plastiques dans l'espace UEMOA: cas du Bénin. Réseau National des Centres de Ressources. Rapport final, Cotonou, Nov., 59p.
Sadeque M, Patil KA (2014). Comparative Study of EVA and Waste Plastic Polymer Modified Bitumen. International Journal of Civil, Architectural, Structural and Construction Engineering. 8(1), 110-113.
Vasudevan RNSK, Velkennedy R, Ramalinga Chandra Sekar A, Sundarakannan B (2007). Utilization of Waste Polymers for Flexible Pavement and Easy Disposal of Waste Polymers. In: Proceedings of International Conference on Sustainable Solid Waste Management, 5-7 September. Chennai, India. pp. 105-111.
Verma SS (2008). Roads from Plastic Waste. Indian Concrete J. 18-04-13 GTR 236 29. Nov. 43-44.
Yazoghli-Marzouk O, Dheilly RM, Queneudec M (2005). Valorisation des déchets d'emballages plastiques dans les matériaux de construction. Récent Progrès en Génie des Procédés, n° 92. Editions SFGP, Paris (France). ISBN 2-910239-66-7.