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Application of Bottom Ash for Pavement Binder Course

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Abstract

In Europe, bottom ash (BA) is used in road construction as a fill material, mainly in embankments. The use of bottom ash as an aggregate in asphalt concretes is still in the early stages. The paper describes the results of tests performed at the Polytechnic of Bari on asphalt concretes containing BA coming from ENEL Spa plants in Brindisi (Italy). Asphalt concretes made using BA mixed with local aggregates, were evaluated. In particular, a specific attempt was done in order to evaluate the applicability of this technology for the production of the binder layer in surface course.

Keywords: Bottom Ash; diffraction analysis; binder course; stability; Cantabro

1. Introduction

The Bottom Ash (BA) is a Coal Combustion Products (CCP). Most of CCP produced in Europe are used in the construction industry, in civil engineering and as construction materials in underground mining (52.4 %) or for restoration of open cast mines, quarries and pits (35.9 %).

The first types of ashes produced by coal-fired power plants that have been studied and re-used were the fly ash. They are successfully used in concrete production for over fifty years. In the U.S.A. more than six million tons and in Europe more than nine million tons of fly ash are used annually in cements and concretes. Even in Italy the fly ash are used almost entirely (over 90%) in the production of cements and concrete mixtures, materials in which the ashes provide their best technical and economic contribution. As for the BA, in Italy the situation is quite different. The demand for the BA is small in the constructions works and most of the BA is not used. In the rest of Europe (north Europe) and in U.S.A. the situation is dissimilar as BA is largely used [1], [2]. Figure 1 [3] reports the ECOBA statistics of CCPs production, utilization and disposal in Europe in 2003.

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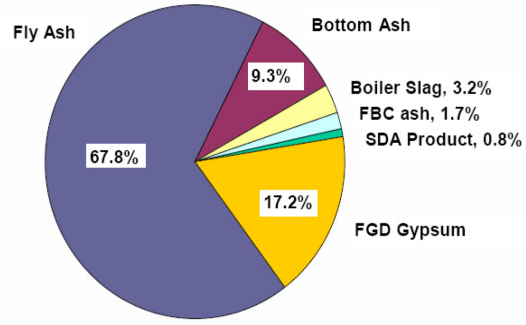


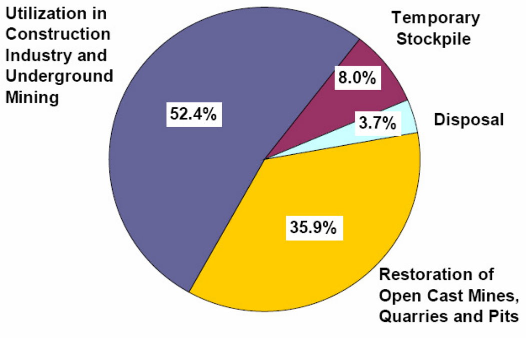


Fig. 1 – (a) Production; (b) utilization and disposal of CCPs in Europe (EU 15) in 2003 [3]

Bottom ash is produced as a granular material and removed from the bottom of dry boilers. It is much coarser than fly ash and it is also formed during the combustion of coal. In 2003 about 6 million tons of bottom ash was produced in Europe. About 2,7 million tons of bottom ash was used in the construction industry. 48% of this was used as fine aggregate in concrete blocks, 33% in road construction and about 14% in cement and concrete.

In Italy the technique of using BA in road construction is not diffused, especially for the production of asphalt mixes. As consequence no technical norms or regulations have been ruled about its use. The re-use of bottom ash could spread in Italy if specific norms and regulations would exist. In particular, this paper reports of some technical investigations on the use of BA as part of a bituminous mixes for the binder course. After an overview of the Italian and European norms and of the US state of the art, the paper gives the results of the study an such materials curried out for the ENEL S.p.A.

2. Overview of the Italian and European Norms

The possibility of reusing ash from power plants contributes directly to implement the two main points of the Community Strategy in terms of disposal and waste management: prevention and recovery. In Italy the management and disposal of waste is governed by D.L. n. 152 of 03/04/2006 [4], which contains the norms as required by the law 308/2004. According both to the definitions of the waste materials given by the D.L.152/06 and the classification adopted by the E.W.C. (European Waste Catalogue), the coal ash can be considered as non-hazardous special waste. In particular, the bottom ash is identified with the E.W.C. code 10.01.01. The D.L. 152/2006 retains the principle of “hierarchy of waste management” adopted by European States that establishes in general a “priority order” of what constitutes “the best environmental option in legislation and policy waste”: first to prevent that a material became waste, than recycling, classic recovering and other forms of recovery, and finally disposal.

In Italy, the recovery activities for special non-hazardous waste, including ash, are governed by the D.M. of 05/02/1998 [5] and subsequent amendments and additions.

Currently there are many national and European standards giving the acceptance requirements for the of the fly ashes. In particular the use of fly ash in roads construction is regulated by the UNI EN 14227 - 2004.

Regarding the specific use of bottom ash in the road construction the Italian legislation does not provide exact information. The only reference are the following European standards providing general instructions for the use of recycled material in civil and road constructions:

- UNI EN 13242 (2004) giving of the technical properties of the "aggregates obtained from natural or industrial processes or recycled" both unbound and bound mixtures with hydraulic binders for this use in civil and road constructions [6].
- UNI EN 13043 (2004) giving the requirements for the aggregates and fillers obtained by processing either natural materials, industrial materials or recycled materials for bituminous mixes [7].

Table 1 provides the set of laws and standards that can be taken as a reference for the use of BA in road constructions in Italy.

Table 1 – references for the use of bottom ash in Italy

Type of regulation	Bottom ash
waste management	D.L. 152/06 part VI (CER code 10.01.01) [4]
recovery procedures	D.M. 05/02/1998 and subsequent amendments and additions (production of concretes, bricks, expanded clay) [5]
technical requirements (UNI EN)	absence of specific laws (UNI EN 13242 - 2004) (UNI EN 13043 - 2004) [6],[7]
standards for road construction and aggregates acceptance	ANAS specifications [8] CNR 139/92 (for aggregates of bituminous mixes) [9]

3. U.S. experiences in the use of bottom ash in HMA

In the United States the use of coal ash in civil engineering works and in particular in road constructions has been in use for over seventy years. The first example of recovering fly ash for use as filler in asphalt and concrete mixtures dates back to 1930. The first large-scale use of fly ash in concretes was when the Hungry Horse Dam (Montana) was constructed in 1949. However, the use of bottom ash in HMA is more recent. The state of West Virginia, between 1971 and 1976 produced more than 200 miles of rural roads using a mixture of bottom ash and bitumen called “Ashphalt”, which was followed by the first scientific publication related to the use of this ash in bituminous mixes [10].

The use of coal ash increased over the last decade due to increased production of electricity from coal.

In the U.S. the ash produced by coal combustion is not considered hazardous waste at the federal level. Anyway there is not a clear regulation on its use, yet. Every State has a different regulation for the classification and the use of coal ashes.

The large industrial groups linked to the production of electricity from coal are located in Texas, Florida and Pennsylvania; they gave great effort in promoting the use of the CCP, removing barriers to their use and in writing clear regulation.

Up until now, coal ash has been excluded from the list of hazardous waste contained in the Resource Conservation and Recovery Act (RCRA) in 1979 and subsequent studies have shown the material to be innocuous.

Recent studies have indicated that bottom ash may have desirable engineering properties and will not degrade bituminous mixes performance properties when used to replace a portion of the fine aggregate in an asphalt mix [11]. No more than 30 percent BA as an aggregate replacement is recommended, mixes with 50 percent or more BA in asphalt pavements were found to have unacceptable stabilities [12]. In a study where 15 percent bottom ash replaced aggregate, bituminous mixes prepared with bottom ash did not show any significant degradation in performance when compared to control mixes. In the study the bituminous mixes maintained desirable strength, low temperature, and rutting properties.

The addition of bottom ash in the mixes requires an increase in asphalt content [13]. And, in West Virginia, there have been problems with paving mixtures containing bottom ash in which pyrite contamination was not been considered. Pyrite particles tend to weather during the life service, despite they are coated with asphalt, causing popouts and deep red stains in the pavement surface [14]. Therefore, iron pyrites should be removed before bottom ash is used as an aggregate replacement material [11].

The Environmental Protection Agency (EPA) in May 2010, for the first time after several years of use of the CCPs, has proposed a law to regulate their use and currently has suspended the "C2P2 program" pending the legislation on the ash management should be approved [15]. EPA intends to allow the use of bottom ash only as constituents in bituminous or concrete mixtures, where the ashes are not free, as in soil stabilization or in road embankments, but they are "imprisoned" in the mixtures matrix. Therefore, even in America as in Italy and other European countries, despite the widespread use of ashes for a long time, it appears that there are difficulties to apply clear regulations and standards on the use of ashes. The need for a legislation able to give standards on the use of coal ash arises. For many years, the U.S. Department of Transportation has allowed the use of CCPs in flexible pavements courses without specific standards. At the present the AASHTO and ASTM design requirements serve as a technical reference, despite not readily applicable to ashes because intended for natural aggregates.

In conclusion, the various U.S. agencies converge on the need to establish new regulations that indicate performance rather than prescriptive standards, encouraging a greater use of coal ash in asphalt and concrete mixtures, with major environmental and economic benefits, as well as in performance.

The Recycled Materials Resource Center (RMRC) has recently issued the guidelines for the use of recycled materials, with particular attention to the coal ashes, based on experience and research developed in recent years in various universities and in various U.S. States [16]. It gives valuable guidelines for the use of bottom ash in bituminous mixes. The guide underlines that, due to the low resistance, the bottom ash is more suitable to be used in base courses than in the superficial layers or in the construction of road embankments. Bottom ash in fact has been used mainly in cold mix asphalt for roads with low traffic volume, limited to the base courses where the performance requirements for durability and strength are not as high as in the surface layers.

The RMRC introduces requirements that bottom ash (and boiler ash) should have included in the HMA:

- cleaning: in addition to treatments commonly carried out in plants (desulfurization, etc.) the ashes should be treated to reduce the amount of pyrite causing degradation of the materials in presence of water;
- grain size distribution: bottom ash need to be cleaned of dust in order to ensure the correct aggregate gradation;
- drying: the bottom ash have to be dried before being used to remove humidity linked to the production process. Excessive wet content can reduce the reliability of asphalt mix courses: it causes emptying of the mixture with consequent degradation of the HMA courses.

4. Why to consider the binder course

Bottom ash may contain pyrites or lightweight, porous "popcorn" particles which are not an ideal aggregate source in bituminous mixes, especially for wearing courses [16]. As stated above, the presence of pyrites causes many deficiencies to the HMA when it is in contact with water and air. This is one of the reasons that made the use of bottom ash advisable only for intermediate courses. The other reason is the high values of the Los Angeles coefficient that this material presents. For these reasons most of the applications of bottom ash are in the base courses. No applications are known to the Authors for the binder course.

In the work being presented in this paper an attempt was done to use the bottom ash for producing bituminous mixes for the binder layer.

5. Materials used for the preparation of test specimens

The BA used for the experiments are those coming from the ENEL coal power plant in Brindisi (Italy) and are pyrite free.

The first step of the work was the characterization of the aggregate. Hence the granulometric analysis of the BA and local natural aggregates was performed together with the Los Angeles test. Figure 2 shows the results of these tests. The bottom, ash was found to have a Los Angeles L.A. = 55%, quite higher than natural aggregates.

These were limy-dolomitic particles selected among those available in the area of Brindisi. They show good physical and mechanical characteristics, resulting good materials for pavement constructions. They have always shown LA <25%, which is the minimum required by the ANAS (the Italian main agency managing the public highway network) specifications [8].

With regard to the asphalt, it was a 50/70 dmm pen, supplied by local plant; it meets the requirements of the UNI EN 12591 standards [17]. Penetration test and softening point performed in the laboratory gave 57 dmm and 53°C respectively.

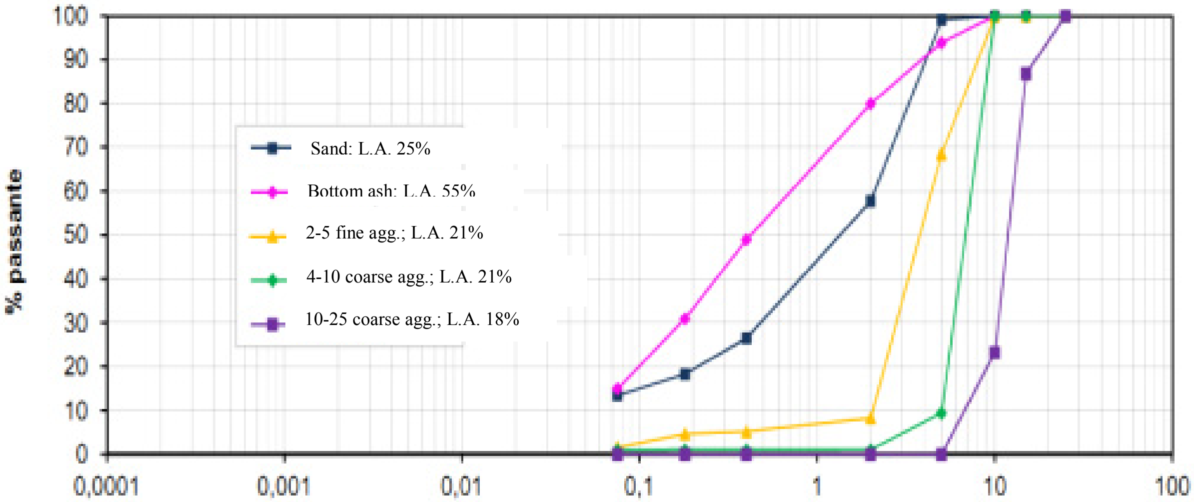


Fig. 2 - aggregate gradations and results of the Los Angeles test

6. X-ray diffraction analysis of bottom ash

The bottom ash was examined with x-ray diffraction analysis. This test allows to identify the crystalline compounds present in a solid material. The material tested is mounted on a goniometer and gradually rotated while being bombarded with X-rays, producing a diffraction pattern of regularly spaced spots known as reflections. The spectra obtained allows to identify the composition of bottom ash.

The results of the test are shown in the figures 3 and 4. The most considerable compounds are: Anorthite (CaO.Al2O3.2SiO2, an alumino-silicate of calcium); Mullite (Al (4 +2 x) Si (2 +2 x) O (10-x), an aluminum silicate; Quartz (SiO 2, a silicon oxide); Hematite (Fe2O3, an iron oxide). All these materials are generated by reaction, at high temperature in the boiler, between the different oxides of the metals constituting the major impurities present in the coal. These are compounds known to be not sensible to water, with a considerable strength, and brittle. The latter propriety of these compounds is the responsible of the high value obtained with the Los Angeles test. (LA=55%).

The pyrite, if present, is definitely less than 1% (percentage relative to the test tolerance). The absence of pyrite might be justified by the different origin of the coal, compared to that used in the US, and, although to a lesser extent, by the different combustion cycle. This result induced the Authors to try the use of BA in the binder course rather than in the base course. If it is suitable for the binder course it would be suitable also for the base course.

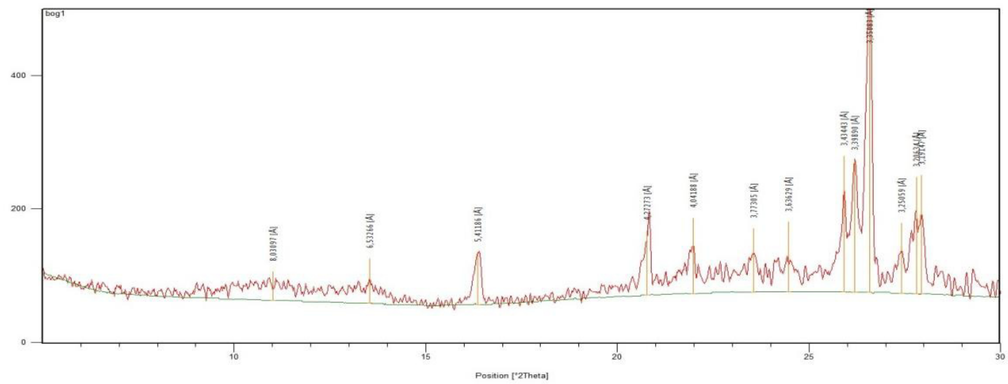


Fig. 3 - x-ray diffraction spectra of bottom ash from 0° to 30°

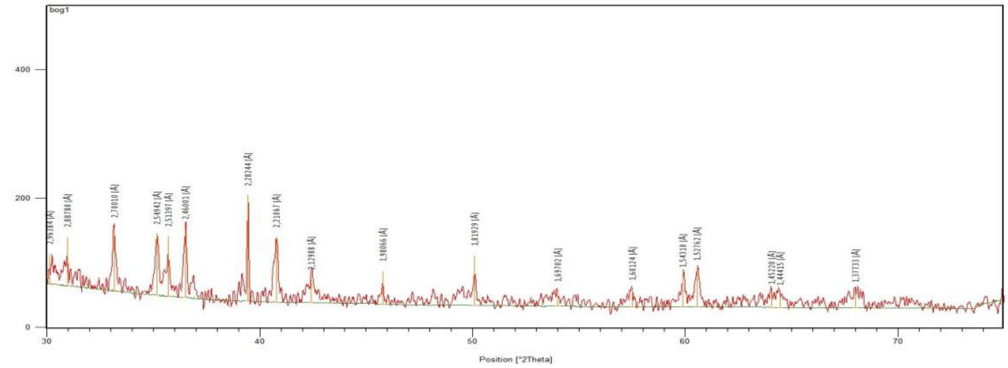


Fig. 4 - x-ray diffraction spectra of bottom ash from 30° to 75°

7. Mix design

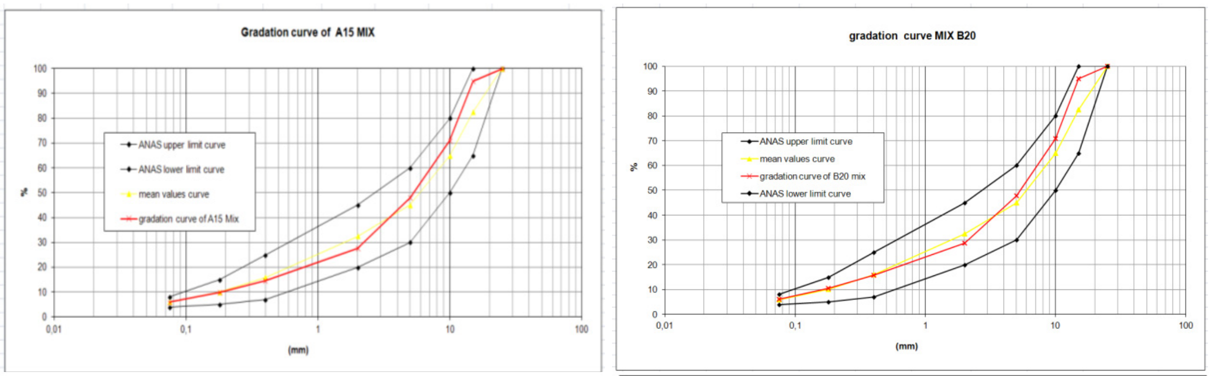
The mix design was performed with the aim of producing samples with different BA content. The BA always replaces part of the sand fraction of the aggregate. This way three different series of samples were produced.

The reference aggregate gradation selected for the test is the ANAS binder course whose aggregate gradation limits are represented in the Figures 5 and 6b. The final aggregate selection was done in order to make the gradation curve stay as much as possible in the middle of the gradation ranges. The mix of the single fractions used to compose the final gradation curve is summarized below and is detailed in Figures 5 and 6a.

- *design curve A15*: 15% of bottom ash (by weight); 25% of sand; 12% 2-5 mm fine agg.; 10% 4-10 mm coarse agg.; 38% of 10-25 mm coarse agg.;
- *design curve B20*: 20% of bottom ash (by weight); 20% of sand; 12% 2-5 mm fine agg.; 10% 4-10 mm coarse agg.; 38% of 10-25 mm coarse agg.;
- *design curve C25*: 25% of bottom ash (by weight); 15% of sand; 12% 2-5 mm fine agg.; 10% 4-10 mm coarse agg.; 38% of 10-25 mm coarse agg.

As stated above, the bottom ash was introduced in the mix as part of the fine aggregate by replacing part of sand content. This was done with respect to the U.S. experiences [1], [2], [11]. Recent studies have shown that the use of bottom ash in bituminous mixes in place of the fine fraction of natural aggregates does not change the mix technical performance [3]. It is also recommended that BA is to be added at a maximum of 30% by weight as higher percentage can cause problems of instability unacceptable for flexible pavements. When BA is used in 15% by weight no performance problems have been detected.

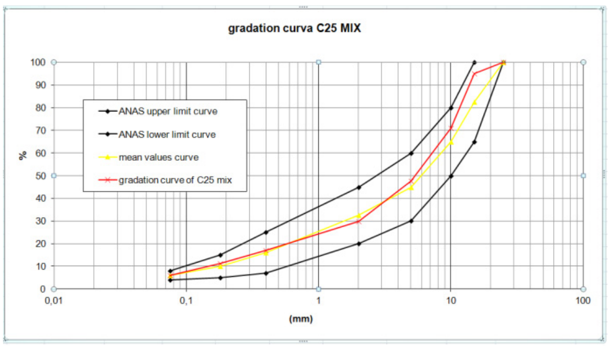
In the figures 5 and 6a the three curves are shown together with the main characteristics of aggregates (that are shown in figure 6b). For each mix the figures report the LA coefficient of the mix (LAmix), calculated as the weighted mean of the Los Angeles coefficient of each aggregate fraction. We can observe that the LAmix is always between 25% and 30%. As expected, the LAmix increases on increasing the BA content. The authors have considered LAmix = 30% as the upper limit for the acceptance of the aggregate mix for the construction of binder courses. This is challenging as the ANAS and others major Agencies require a maximum of LA = 25% for the aggregates of the binder courses. This, together with the recommendations in [2],[3] convinced the researchers to not exceed in 25% in weight of BA in the mixes. The idea is that on replacing only a small percentage of sand with a soft aggregate such the BA, the mechanical behavior of the final HMA would not drop below the limits of acceptance.



LOS ANGELES TEST A15 MIX						
	BOTTOM ASH	10-25 COARSE AGG.	4-10 COARSE AGG.	2-5 FINE AGG	SAND	A15 MIX
%	15%	38%	10%	12%	25%	100%
LA %	55	18	21	21	25	25.96

LOS ANGELES TEST B20 MIX						
	BOTTOM ASH	10-25 COARSE AGG.	4-10 COARSE AGG.	2-5 FINE AGG	SAND	A15 MIX
% in peso	20%	38%	10%	12%	20%	100%
LA %	55	18	21	21	25	27.46

Fig. 5. (a) A15 granulometric curve and L.A. coefficient; (b) B20 granulometric curve and L.A. coefficient



LOS ANGELES TEST C25 MIX						
	BOTTOM ASH	10-25 COARSE AGG.	4-10 COARSE AGG.	2-5 FINE AGG	SAND	A15 MIX
%	25%	38%	10%	12%	15%	100%
LA %	55	18	21	21	25	28.96

Fig. 6. (a) C25 granulometric curve and L.A. coefficient; (b) Natural aggregates and bottom ash for A15 mix

An asphalt content of 4,5% was selected for all mixes. This content is in the range of both the ANAS specifications [8] (4.0-5.5%) and the Autostrade specifications [18] (4.5-5.0%). This way the number of variables of the study was reduced. The selected percentage is slightly higher than the calculated minimum required content as it was supposed that a higher asphalt content could improve the mechanical response of the mixes containing BA. In this regard, in order to evaluate the influence of asphalt on the mixes, a sample with 20% of bottom ash and 5% of asphalt content was produced.

So a total 5 series of specimens were produced: a first one with no BA, other 4 through the replacement of a percentage of sand respectively of the 15%, 20% and 25% with an equal content of BA (the sample with 20% of BA was manufactured with 2 asphalt contents: 4.5 and 5.0%). These mixes are labeled A, B and C respectively. This way the mechanical behavior of the mix can be observed on varying the BA content.

Each mixture was associated with the alphanumeric code Zn_m where:

- Z corresponds to the graduation curves A, B o C;
- n corresponds to the bottom ash percentage (ranging from 0% to 25%)
- m corresponds to the asphalt ratio expressed in ‰ in weight (45 or 50).

The following mixes were produced: A15_45, A00_45, B20_45, B20_50, B00_45, C25_45 and C00_45. With this mixes, Marshall specimens were produced both at 50 and 75 blows. Each specimen was identified with the alphanumeric code xy_Zn_m_t where:

- xy indicates the sequence number of the specimen;
- Zn_m is the code (as defined above) of the bituminous mix;
- t denotes the number of blows (50 or 75).

A convenient number of specimens was produced for each of the mixtures listed above in order to carry out the tests of the mechanical characterization of the bituminous mixes.

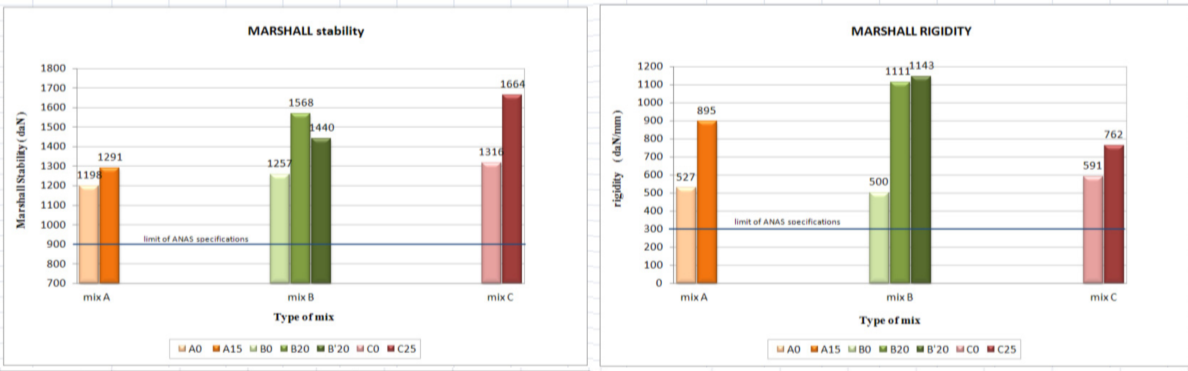
Marshall and Cantabro tests were performed on the samples.

8. Results

The experimental data indicate good mechanical properties of the mixes with bottom ash. The specimens prepared gave performance values within the limits required by the ANAS specifications [8], almost equivalent to the traditional mixes. These results are summarized in the following tables and graphically represented with histograms. Figure 7a shows the results of the stability test, Figure 7b the Marshall rigidity, Figure 8a shows the Cantabro wearing loss and, finally, Figure 8b shows the void contents.

The results of the Marshall test, for all the mixtures, show that the stability (S) is always higher than the lower limit required by the ANAS specifications, S=900 daN. In particular, on increasing the BA content in the mixture, the stability goes from S = 1,291 daN (when ash percentage is 15%) to S = 1,664 daN (when ash percentage is 25%). The value of the Marshall rigidity (R), much larger than the imposed ANAS limit (R =300 daN), appears to confirm the positive effects of the bottom ash in the bituminous mixtures.

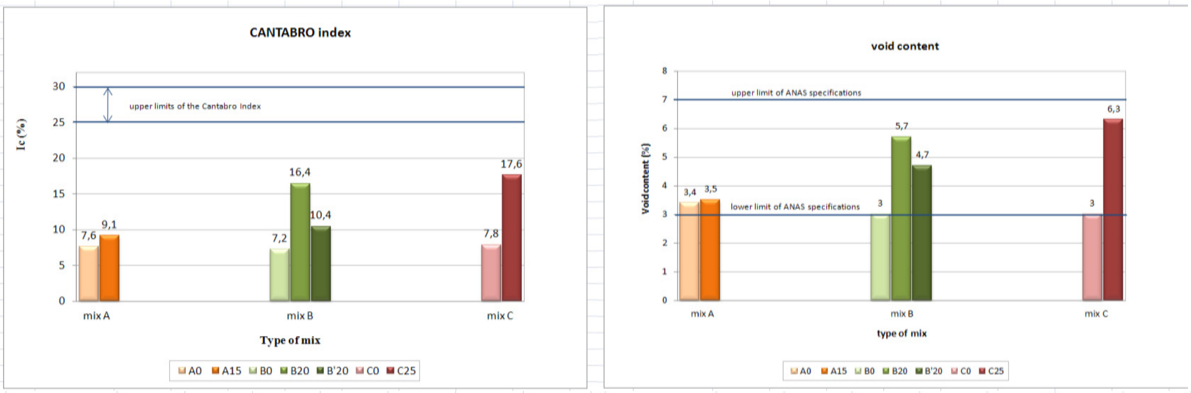
From the comparison of the Marshall stability between the mixture with 15% of bottom ash (A15_45_75) and for the mixture with only natural aggregates (A00_45_75), it appears that the two mixtures behave in a similar manner: the stability does not vary significantly (S=1,198 daN for the A00_45_75 and S=1,291 daN for the A15_45_75). Therefore, the introduction of the bottom ash as part of the fine sand in a percentage of the 15%, does not modify the mechanical characteristics of the bituminous mixture. Conversely, a greater influence can be observed when higher percentages of bottom ash (20% -25%) are introduced in the mixture; while in the specimens packed with 15% of ash, the stability does not increase significantly (less than the 10%), in the samples packed with 20 and 25% of ash, it increases more (20% approximately). The Marshall stability is greatly increased when BA increases from 15% to 20%, while it is almost constant when the percentage of ash goes from 20% to 25%.



Type of mix	Mix A		Mix B			Mix C	
code	A0	A15	B0	B20	B'20	C0	C25
% natural aggr.	100	85	100	80	80	100	75
% bottom ash	0	15	0	20	20	0	25
% asphalt	4,5	4,5	4,5	4,5	5	4,5	4,5
Stability (daN)	**1198**	**1291**	**1257**	**1568**	**1440**	**1316**	**1664**
ANAS specific. limit	≥ 900 (daN)						

Type of mix	Mix A		Mix B			Mix C	
code	A0	A15	B0	B20	B'20	C0	C25
% natural aggr.	100	85	100	80	80	100	75
% bottom ash	0	15	0	20	20	0	25
% Asphalt	4,5	4,5	4,5	4,5	5	4,5	4,5
Rigidity	**527**	**895**	**500**	**1111**	**1143**	**591**	**762**
ANAS specific. limits	≥ 300 (daN/mm)						

Fig. 7. (a) Marshall stability results; (b) Marshall rigidity



Type of mix	Mix A		Mix B			Mix C	
code	A0	A15	B0	B20	B'20	C0	C25
% natural aggr.	100	85	100	80	80	100	75
% bottom ash	0	15	0	20	20	0	25
% asphalt	4,5	4,5	4,5	4,5	5	4,5	4,5
IC (%)	**7,6**	**9,1**	**7,2**	**16,4**	**10,4**	**7,8**	**17,6**
upper limits	25 ÷ 30 %						

Type of mix	Mix A		Mix B			Mix C	
code	A0	A15	B0	B20	B'20	C0	C25
% natural agg.	100	85	100	80	80	100	75
% bottom ash	0	15	0	20	20	0	25
% asphalt	4,5	4,5	4,5	4,5	5	4,5	4,5
void content	**3,4**	**3,5**	**3**	**5,7**	**4,7**	**3**	**6,3**
ANAS spec. limits	3 ÷ 7 %						

Fig. 8. (a) Cantabro test results; (b) Void content

The tests showed also that in the sample with 20% of ash and 5% of asphalt (B20_50_75) the stability decreases, even if it is still higher than the lower limit required by ANAS specifications.

The same samples showed also a void content between 3 and 7%, according to the ANAS specifications. The greater the amount of ash, the grater the void content. Therefore, the mixtures with greater contents of ash require a greater amount of asphalt. That is confirmed by the comparison between the samples produced with 20% of BA and 4.5% of asphalt (B20_45_75), and the samples produced with the same BA content and 5% of asphalt (B20_50_75): an increase in the asphalt content of 0.5% gives a significant reduction (about 0.8%) in the void content which goes from 5.7% (B20_45_75) to 4.7% (B20_50_75).

The difference in voids content between mixtures with and without BA, similarly to what observed for the Marshall stability, is not appreciable for a 15% BA content, while it is significant with the higher BA content (20% and 25%). This result confirms the need for use a greater asphalt content in the mixtures with high amounts of ash in order to ensure a better adhesion between the asphalt and particles.

The specimens used for the Cantabro test show a fairly good wearing resistance. The Cantabro Index (Ic) is less than 25 for all the mixes but one that (anyway) showed Ic < 30%. In fact, commonly mixes with Ic < 25-30% are acceptable for the intermediate layers of a pavement [8], [18], [19]. At low values of ash content correspond rather low weight losses (9.1% for the A15_45_75) comparable to those obtained for natural aggregates mixture (7.6% for the A00_45_75). On the contrary, when the percentage of ash increases, a worsening of the wearing loss resistance was observed: the value of the Cantabro Index lies between 16-18% for the mixture with 20% of ash (the B20_45_75) and for the mixture with 25% of ash (the C25_45_75), respectively. This worsening is also evident when comparing the values obtained for mixtures B20_45_75 and C25_45_75 to the corresponding mixtures with natural aggregate (the B00_45_75 and the C00_45_75).

As expected, on increasing the asphalt content the Ic decreases: the Ic goes form Ic=16.4 for the 4.5% of asphalt content, to Ic=10.4 when the 5% of asphalt content.

The experiments show that the bottom ash improves the stability while reducing the wearing resistance. For this reason the hypothesis of using BA for the wearing course is to be discharged. The reduction in the characteristic of wearing resistance, however, can be compensated with an increase in the content of asphalt in the mixture, as demonstrated by the Cantabro results on specimens with 20% of ash and 5% of asphalt content.

9. Other environmental tests

In order to verify the possibility of using bottom ash as a recycled material (or, better, recovered material) in HMA, according to the D.M. n. 186, 05/04/2006, also leaching tests were performed. This test is required in order to use waste construction materials (including those containing BA) in the embankments, road base, landfill cover, etc. . So the recovery of bottom ash as an aggregate in HMAs is subject to verification of compliance with the limits specified in the norm.

A leaching test was carried out for all the samples and the results show that none have released quantity of substances exceeding the limits set by law. Almost all the samples gave results below the limits of detection and, for those where some amount was detected, it was very below the superposed limit.

In conclusion, the test results indicate, unquestionably, that this type of ash can be used, together with the already planned uses, even in the asphalt mixtures for flexible pavements, without risk of the release of dangerous substances into the environment, due to the runoff.

10. Conclusions

The experiments show the applicability of bottom ash for the production of HMA to be used in the intermediate courses of the flexible pavements (in particular binder course). The tested mixes were produced with lime-dolomitic aggregates coming from Apulia and asphalt 50/70.

Best results have been achieved when a 15% of BA was added to the mix replacing a correspondent amount of sand. The more the asphalt content, the more the wearing resistance of the mixes.

The test results indicate that there is no worsening in mechanical characteristics of the asphalt mix in comparison to the conventional reference mix. It means that BA could be added among the recoverable materials defined by the Italian law (D.M. 05/02/98). However, to encourage the use of this recycled material, it is necessary to issue new standards giving new design criteria based on the mix performances.

Further experiments are needed especially as regard the large scale production of these mixes in order to a correct environmental assessment of the use of bottom ash use in bituminous mix and to properly identify the costs and benefits ratio.

Apart from the environmental benefits of reducing both the consumption of natural aggregates and the amount of ashes to waste, also the economic cost of the reuse of these ashes should be deeply investigated. The need of storing and transport properly these materials could lead to significant cost.

It should be underlined that the Los Angeles coefficient of bottom ash is poor (LA=55%). This makes this material unacceptable for the use in surface courses and worries the plant manager as it produces a large amount of fillers that could clog the filters of the plants. The filler should be treated as a special waste with additional costs for managing it.

Anyway the mechanical and chemical properties of the tested asphalt mixes confirm the possible use of bottom ash in the binder course while additional investigation are required in order to evaluate both technical and environmental aspects together with costs associated with the use of these material in the industrial scale.

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