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Special Issue
Recycling Waste in Construction Materials

Edited by
Dr. Jessica Giró Paloma and Prof. Dr. Joan Formosa Mitjans

MDPI

https://doi.org/10.3390/app10103465

applied sciences

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Use of Unbound Materials for Sustainable Road Infrastructures

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Received: 29 January 2020; Accepted: 14 May 2020; Published: 17 May 2020

Abstract: The growing environmental sensitivity and the reduction of natural resources create, in Italy and other developed countries, an increasing interest in the search for alternative materials to be used in road construction works. In recent years, the problems related to environmental sustainability have made it increasingly difficult to remove natural aggregates from quarries and, at the same time, the regulations for the management of waste dumps are more and more restrictive. For this reason, the use of recycled aggregates is experiencing a continuous increase in the civil construction sector. This paper deals with the study of construction and demolition waste (CDW) in the field of road construction, in particular for the construction of embankment, road subgrades, foundation layers and unbound bases for flexible superstructures. Three different particle size fractions were used to prepare the mixtures: the first having a coarse size and designation 0–63 mm, the second intermediate size with aggregates of 0–31.5 mm grain size and the third with the finest aggregates having a grain size of 0–4 mm. The study was carried out by analyzing three granulometric fractions, verifying the best application for each of them. Subsequently, the mix-design was investigated, operating in compliance with the requirements imposed by UNI 11531-1, EN ISO 14688, EN 13242 and EN 13285. For the unbound layers of subgrade, foundation and base, which require greater resistance to fragmentation, the use of CDW alone has shown some limitations. Therefore, in the experimentation, it was decided to mix the CDW with a granulated slag coming from the steel production in the electric arc furnaces (EAF) and with an additional CDW (0–31.5 mm) coming from the recovery of concrete with slag. EAF granulated slag was used in small quantities, due to its relatively high cost. Four eco-friendly and recycled mixtures were studied, with low economic impact and high environmental sustainability, suitable for the construction of unbound layers of road superstructures.

Keywords: environmental sustainability; road embankment; foundation; CDW; EAF slag

1. Introduction

Construction and demolition waste constitute a very wide and varied range of materials. The fraction that contains concrete and bricks is the more suitable to be employed as a replacement for natural aggregates in several applications, including fillings, subgrades, foundation layers and bases of road pavements [1].

The purpose of this paper is to define the optimal mix design of the mixtures to be used in road embankments, foundations and unbounded bases, according to the UE standards. Therefore, this study evaluates the use of recycled aggregates (construction and demolition waste (CDW) with eventual addition of electric arc furnaces (EAF) slag) as partial substitutes for natural aggregates to achieve environmentally sustainable mixtures.

According to Eurostat 1, construction and demolition waste (CDW) constitutes, in absolute terms, the most significant flow of special waste produced in Europe. It has been estimated that in Europe 820 million tons of CDW are produced yearly and they represent about 46% of the total waste. For 2016, waste production in the EU was around 900 million tons (Mt), compared to 2014 (858 Mt). This value represents about 35% of the total EU special waste production of the same year [2]. For this reason, the European Commission has given priority importance to the management of CDW and has proposed to decrease the weight of CDW recycling by at least 70% by 2020 [3].

One of the most popular and suitable applications of CDW deals with the production of recycled aggregates [4–7] for road construction (embankments, pavement foundation layers and pavement unbounded bases) [8–14]. Their employment is gaining a growing interest due to their environmental and economic benefits [14–16].

Several studies in literature have also highlighted that the substitution of natural aggregates with the artificial ones results in a decrease of the mechanical strength [17–21] while in other studies their employment improve the properties [22]. In addition to CDW and other several waste materials such as recycled glass [23], waste polyurethane foam [24] and used tyres [25], used in pavement layers, EAF slag is also employed in bituminous layers as natural aggregates substitute in subbase and base layers [26–32] in unbound layers. Another technique that recycles used aggregates for employment in road pavements is the reclaimed asphalt pavement (RAP) [33] and the soil-cement, which employs existing material on the layout of the road, preserving the quarries [34].

The recycling process and the chemical composition of aggregates strongly affect their final properties; therefore, it is important to improve the recycling process that has several benefits including the demand reduction for new resources, the reduction of production energy costs, and the possibility to recycle waste which would otherwise be landfilled [35,36]. It is well known that the granulated slag is not only a by-product, but also has an excellent resistance to fragmentation [37,38]. Its use in this field allows one, therefore, to reduce the exploitation of limited natural resources (natural aggregates) and to reduce the potential quantities of waste.

Considering that, in 2013, Italian steel production amounted to 27.3 million tons, of which about 17.9 million tons came from EAF, a production of over 3 million tons of slag per annum was recorded [39]. Data for 2010 show that the slag coming from the electric furnace cycle was used above all for the construction of road subgrades (38%) and cement concretes (28%), while the other part was employed for the construction of asphalt concretes (13%) and of road embankments (13%) [40].

2. Reference Standard

The reference standard of this study is the UNI 11531-1 [41], which defines, in detail, the instructions for the application of the EN ISO 14688 standards in Italy and provides a classification of the soils. This standard specifies the limits and the criteria for use in the road and railway infrastructures of the aggregates and their unbound mixtures, as per EN 13242 [42] and EN 13285 [43]. In particular, EN ISO 14688-1 [44] and EN ISO 14688-2 [45] establish the general principles for the identification and classification of soils on the basis of the most frequently employed features for engineering purposes. Since the main properties of these materials can vary greatly, the standard provides that a more detailed description and/or classification can be adopted, with respect to what is reported in it.

EN 13242 [42] deals with the properties of aggregates obtained by treatment of natural materials (i.e., artificial or recycled) to be used as unbound materials (or bounded with hydraulic binders), for applications in civil engineering and in road construction. It provides the classification criteria of the material according to geometric, physical and chemical characteristics and prescribes a production control system aimed at satisfying the requirements of the CE marking, while EN 13285 [43] defines the properties of unbound mixtures employed for the construction and maintenance of roads, airports and other areas subject to traffic, with appropriate references to EN 13242 [42]. This standard is used for unbound mixtures of natural, artificial and recycled aggregates with maximum dimensions (D), between 8 mm and 80 mm and minimum size (d) equal to 0. Therefore, UNI 11531-1 [41] provides precise indications for the application, in Italy, of the standards cited in the cases of soil covered by EN ISO 14688, present in trenches road subgrades, or used to build embankments and/or subgrade layers; unbound mixtures as per EN 13285 of aggregates, in compliance with EN 13242 intended for civil engineering works and road construction. Moreover, UNI 11531-1 is a useful reference for the drafting of specifications and represents an operational tool of primary importance. It indicates the reference values for the technical characteristics in relation to each destination of use and provides a unitary point of view on unbound materials in civil infrastructures, helping to identify the fields of intervention of each EN standard.

It should be noted that an Italian technical reference, superseded by UNI 11531-1, is constituted by the circular n. 5205 of 2005 by the Ministry of the Environment and of the Protection of the Territory [46]. With reference to the leaching tests, the Italian basic reference standard is the Ministerial Decree 152/2006 [47] and its amendments and additions. The execution of leaching tests was performed according to the standards EN 12457-2 [48] and EN 16192 [49].

3. Materials

The operative phases of the study aim to verify the possibility of using CDW and slag from EAF in the field of eco-compatible road construction. This analysis was divided into two phases: a first phase in which a chemical and a granulometric characterization of materials has been developed, and a second phase in which the suitable mixtures were designed and characterized to be used as embankments, subgrades, unbounded bases and foundation layers.

3.1. Base Materials

Three basic fractions of CDW supplied by INECO s.r.l. (Barile, Potenza, Italy) were employed and tested. The first coarse grain size with d/D designation (d = size of the lower sieve, D = size of the upper sieve) [42] equal to 0/63 mm labelled as A0/63; the second with intermediate grain size, B0/31.5, and the third, the finest one, C0/4 and other two fractions have been added to the basic fractions: a granulated slag from an electric furnace, characterized by a d/D ratio of 4/8 mm and named D4/8 and a CDW coming from concrete with slag labelled as E0/31.5. The fractions of CDW A0/63, B0/31.5 and C0/4 are mainly composed of concrete, bricks, plaster and inert materials.

With reference to the standard EN 13242 [42], the main constituents of the aggregates, about 97%, belong to the following categories: Rc_{32} (32% by weight of concrete) and Rb_{65} (65% by weight of bricks), with $Rcug_{90}$ (Rcug = Rc + Rb + Rg > 90% - Rg % by weight of glass).

The fraction E0/31.5 is characterized by a composition mainly composed of crushed slags (>70% by weight) natural aggregate and cement paste. The granulometric analysis was performed on the examined materials using as series of sieves used the "basic group" (125, 63, 31.5, 16, 8, 4, 2, 1 mm) of EN 13242 [42], suitably integrated by the sieves 0.5, 0.25 and 0.063 mm. The particle size distribution [50] of the examined materials is in Figure 1.

3.2. Leaching Test on the Base Materials

The CDW leaching test is satisfied for all fractions and with reference to the results obtained (Table 1), it can be seen that the aforementioned materials (grouped into three groups, based on common origin, i.e., fractions A-B-C, D and E) are suitable for recovery, as they are classified as non-polluting materials.

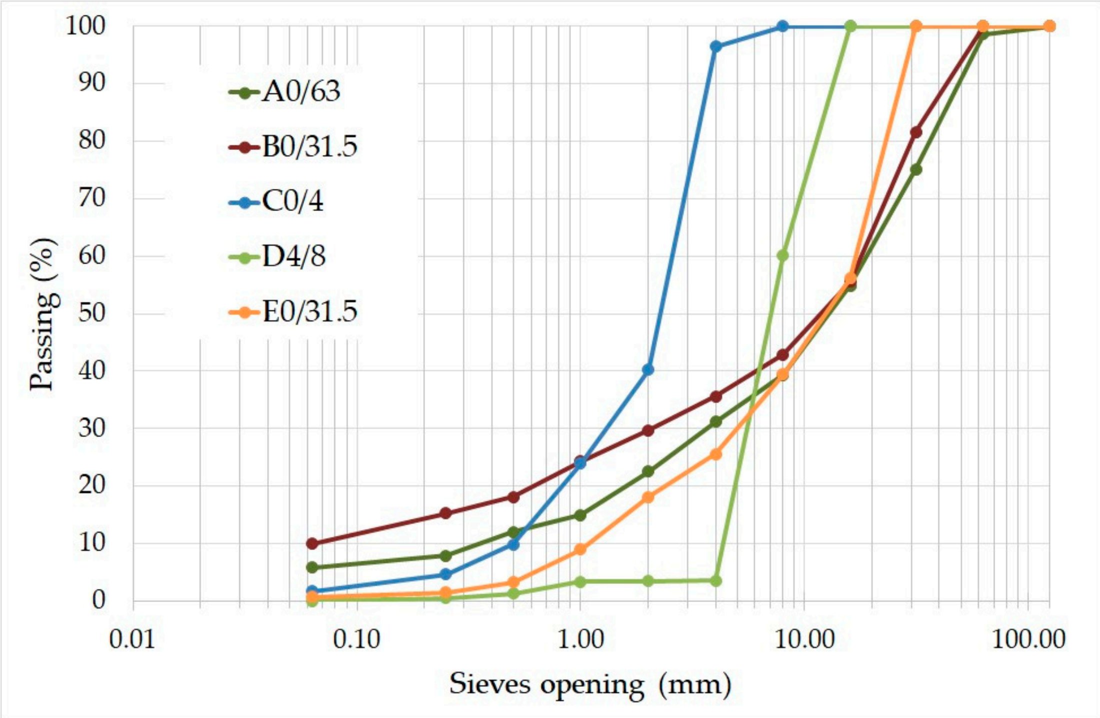

Figure 1. Particle size distribution of base materials.

Table 1. Results of leaching tests on base materials.

Parameters	Units of Measure	Results on the Base Materials			Threshold Limit Value from [23]
		A, B, C	D	E	
pH	pH Unit	8.4	12.5	10.4	5.5–12.0
COD	mg/l	18	17	21	30
Nitrates	mg/l NO_3	5.2	3	4.8	50
Fluorides	mg/l F	0.42	0.2	0.51	1.5
Solfates	mg/l SO_4	33.5	9.2	45.8	250
Chlorides	mg/l Cl	8.6	8.0	26.8	100
Copper	mg/l Cu	0.01	0.04	0.04	0.05
Zinc	mg/l Zn	0.03	0.006	2.7	3
Cobalt	µg/l Co	6.2	2.0	36.7	250
Chromium	µg/l Cr	14.3	8.0	24.8	50
Nichel	µg/l Ni	3.9	5.0	6.8	10
Arsenic	µg/l As	6.3	0.7	5.1	50
Cadmium	µg/l Cd	0.7	0.8	3.8	5
Lead	µg/l Pb	16.4	57	18.2	50

4. Mix-Design of Mixtures and Tests Results

The mix-design of unbound mixtures with recycled aggregates to be used for the construction of embankments, subgrades, foundations, and unbounded bases was developed on the basis of a considerable set of experimental tests. The main laboratory tests carried out in the context of the present study, in addition to the determination of the granulometric category (G_x), the definition of the upper-sieve (OC_x) and the determination of the minimum (LF_x) and maximum (UF_x) content of the finest parts, were the "Los Angeles" test for the evaluation of fragmentation resistance [51] the sand equivalent test [52], the flakiness index [53], the shape index [54] and the CBR bearing capacity test [55].

4.1. Main Standard Requirements of Unbound Mixtures

The main requisites of suitability required of the aforementioned mixtures by the current EN standard [42] are reported in Table 2, while the requisites concerning the particle size distribution and the definition of the control grading envelope are summarized in Table 3 [42,43].

Table 2. Main suitability requirements of unbound mixtures of recycled aggregates.

Characteristic	Standard	Usage			
		Embankment	**Subgrade**	**Unbound Foundation**	**Unbound Base**
Granulometric classification	EN 13285	G_N	G_U	G_A	G_A
Upper-sieve	EN 13285	OC_{85}	OC_{75}	OC_{75}	OC_{85}
Maximum content of fines	EN 13285	UF_{35}	UF_{15}	UF_9	UF_9
Minimum content of fines	EN 13285	-	-	LF_2	LF_2
Mixture designation	EN 13285	0/63	0/31.5	0/31.5	0/31.5
Resistance to fragmentation	EN 1097-2	LA_{50}	LA_{45}	LA_{30}	LA_{30}
Quality of fines	EN 933-8	SE_{20}	SE_{30}	SE_{30}	SE_{50}
Content of cementitious conglomerate fragments, etc.	EN 933-11	$Rcug_{50}$	$Rcug_{70}$	$Rcug_{90}$	$Rcug_{90}$
Content of floating materials: paper, wood, etc.	EN 933-11	FL_{10-}	FL_{5-}	FL_{5-}	FL_{5-}
Flattening of coarse aggregate	EN 933-3	Fl_{50}	Fl_{35}	Fl_{35}	Fl_{35}
Percentage of crushed/rounded particles	EN 933-5	-	-	-	$C_{90/3}$
Sulfate soluble in water	EN-1744-1	$SS_{0.2}$	$SS_{0.2}$	$SS_{0.2}$	$SS_{0.2}$
CBR bearing tests after four days of soaking in water on constipated samples, with humidity ±2% of the optimum at 94% of the maximum density of the modified Proctor test energy.	EN 13286-47	-	≥ 10	≥ 50	-
CBR tests after four days of soaking in water on constipated samples, with humidity ±2% of the optimum at 99% of the maximum density of the modified Proctor test energy.	-	-	-	-	≥ 100

Table 3. Grading envelope requirements of unbound mixtures made of recycled aggregates.

Embankment			Subgrade			Unbound Foundation			Unbound Base		
SO [1] (mm)	Passing LL [2] %	Passing UL [3] %	SO [1] (mm)	Passing LL [2] %	Passing UL [3] %	SO [1] (mm)	Passing LL [2] %	Passing UL [3] %	SO [1] (mm)	Passing LL [2] %	Passing UL [3] %
125	100	100	63	100	100	63	100	100	45	100	100
63	85	99	45	85	100	45	85	100	31.5	85	99
31.5	-	-	31.5	75	99	31.5	75	99	16	55	85
16	-	-	16	50	90	16	55	85	8	35	65
8	-	-	8	30	75	8	35	65	4	22	50
4	-	-	4	15	60	4	22	50	2	15	40
2	-	-	0.063	0	15	2	15	40	1	5	30
1	-	-	-	-	-	1	5	30	0.5	0	20
0.4	-	-	-	-	-	0.5	0	20	0.063	2	9
0.063	0	35	-	-	-	0.063	2	9	-	-	-

SO [1] (mm)	Soil category additional limits A1-a	A1-b	A3
2	50	-	-
0.4	30	50	50
0.063	15	25	10

[1] Sieves Opening; [2] Lower Limit; [3] Upper Limit.

4.2. CDW Mix Design Suitable for the Embankments

In the construction of the embankments, the soils of groups A1-a, A1-b, A3, A2-4, A2-5 and A4 with group index equal to zero can be used [41]. Limited to the lower part of the embankment (i.e., at a distance of at least 2 m from the laying surface of the road superstructure), on the other hand, the soils of groups A2-6 and A2-7 with group index equal to zero can be used, after the construction of a layer capillary of thickness not less than 30 cm. The study of mix design was carried out in full compliance with current legislation [41–43] and this made it possible to validate the suitability of the fraction A0/63 (which appears to belong to the group A1-a), as material for the construction of the road embankment.

This validation derives from the fact that, the aggregate A0/63, not only presents a granulometric distribution compatible with the limits imposed by the standards (Tables 3 and 4) and respects the prescriptions related to the granulometric category to which it belongs (G_N) and oversize (OC_{85}), but also meets all the main requirements that UNI 11531-1 [41] imposes on road embankments, including the limit of resistance to fragmentation [51], considering that its coefficient "Los Angeles" (LA= 45) is lower than the required value (LA= 50). This requirement makes it possible to avoid the use of additional materials such as the EAF (LA = 16), whose function is precisely to increase the aforementioned resistance beyond the minimum values set.

Table 4 shows the particle size distributions of all the proposed mixtures (embankment, subgrade, foundation and base) and the percentages by weight of the five basic fractions a0/63, b0/31.5, c0/4, d4/8 and e0/31.5 (Section 3.1) used to obtain them.

Figure 2 shows the particle size distribution and grading envelope 0/63 GN for the embankment constructed of CDW, according to current European standards [42].

Table 4. Proposed mixtures: particle size distribution and percentage by weight of basic fractions.

Sieves Opening (mm)	Passing (%)			
	Embankment [1] (0/63)	Subgrade [2] (0/31.5)	Foundation [3] (0/31.5)	Base [4] (0/31.5)
125	100.00	100.00	100.00	100.00
63	98.60	100.00	100.00	100.00
45	-	[5]	[5]	100.00
31.5	75.10	86.79	90.46	90.83
16	54.90	65.84	72.53	73.42
8	39.40	55.86	56.30	53.47
4	31.20	49.11	39.16	31.09
2	22.50	31.54	25.19	21.73
1	15.00	23.44	18.52	16.46
0.5	12.00	15.47	11.79	10.77
0.25	7.90	12.17	9.05	8.42
0.063	5.80	7.63	5.58	5.25

[1] Mix design: 100% A0/63; [2] Mix design: 72% B0/31.5 + 23% C0/4 + 5% E0/31.5; [3] Mix design: 52% B0/31.5 + 18% C0/4 + 20% D4/8 + 10% E0/31.5; [4] Mix design: 50% B0/31.5 + 10% C0/4 + 30% D4/8 + 10% E0/31.5; [5] Passing necessarily at 100%.

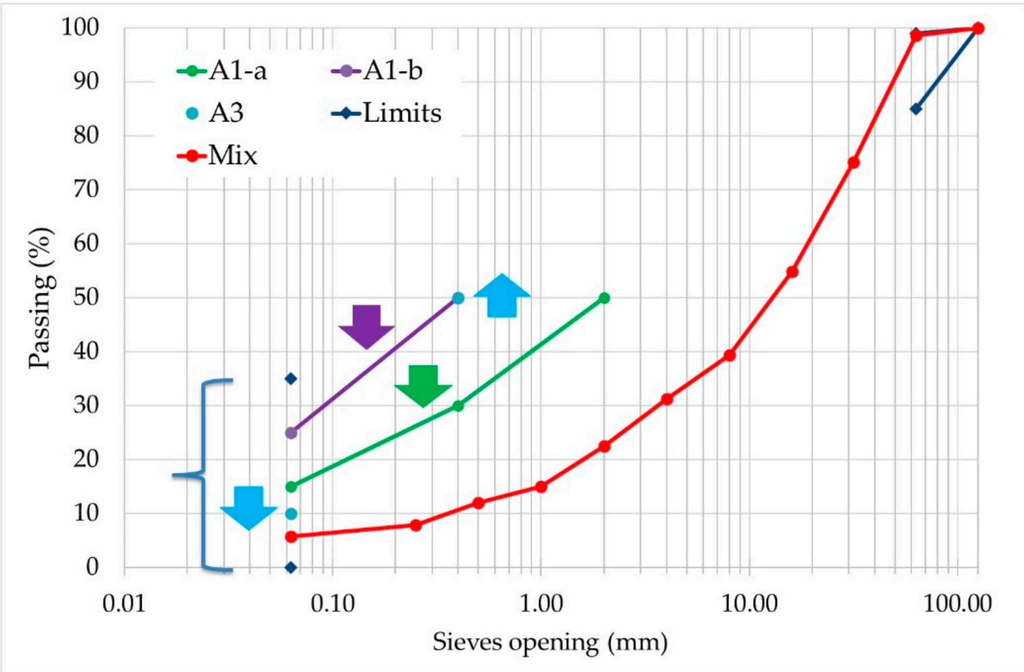

Figure 2. Particle size distribution and grading envelope 0/63 GN for embankment constructed of construction and demolition waste (CDW).

It should be noted that the CDW to be used in the construction of road embankments must have a sand equivalent value greater than 20 (category SE_{20}). The sand equivalent test allows one, conventionally, to characterize the silt-clay fraction contained in the tested material. In this case, the test result [52] provided a value of 47. As regards the determination of the content of various materials, such as cement conglomerates, mortars, natural stone elements, crushed stone, hydraulically bound materials and glass, as well as the content of floating material such as paper, wood, fibers, etc., the test performed on the mixture in examination, respectively, the following values: $Rcug_{90}$ and FL_{5-} [56]. The category of the mixture referred to the flattening of the coarse aggregate [54] was equal to Fl_{20}.

A further laboratory test performed on the material was the determination of the water-soluble sulphate [57], which returned the $SS_{0.2}$ category. The test for the determination of the CBR after four days of water imbibition (carried out even if not explicitly requested by the standards) has instead provided a value of 65% [55]. Considering that the leaching test is also satisfied (Table 1), it can be deduced that the identified mixture (consisting only of the A0/63 aggregate) is suitable to be used as a road embankment; the summary of the experimental results reported according to the EN standards format is reported in Table 5.

Table 5. Results of the laboratory tests on the designed mixtures.

Characteristic	Standard	Results of laboratory tests according to EN standards			
		Embankment (0/63)	**Subgrade (0/31.5)**	**Foundation (0/31.5)**	**Base (0/31.5)**
Granulometric category	EN 13285	G_N	G_U	G_A	G_A
Upper-sieve	EN 13285	OC_{85}	OC_{75}	OC_{75}	OC_{85}
Maximum content of fines	EN 13285	UF_7	UF_9	UF_7	UF_7
Minimum content of fines	EN 13285	-	-	LF_5	LF_5
Resistance to fragmentation	EN 1097-2	LA_{45}	LA_{40}	LA_{28}	LA_{25}
Quality of fines	EN 933-8	SE_{47}	SE_{46}	SE_{71}	SE_{75}
Content of cementitious conglomerate fragments, etc.	EN 933-11	$Rcug_{90}$	$Rcug_{90}$	$Rcug_{90}$	$Rcug_{90}$
Content of floating materials: paper, wood, etc.	EN 933-11	FL_{5-}	FL_{5-}	FL_{5-}	FL_{5-}
Flattening of coarse aggregate	EN 933-3	Fl_{20}	Fl_{20}	Fl_{20}	Fl_{20}
Percentage of crushed/rounded particles	EN 933-5	-	-	-	$C_{90/3}$
Sulfate soluble in water	EN 1744-1	$SS_{0.2}$	$SS_{0.2}$	$SS_{0.2}$	$SS_{0.2}$
CBR tests after four days of soaking in water on constipated samples with humidity ±2% of the optimum at 94% of the maximum density of the modified Proctor test energy.	EN 13286-47	65%	65%	70%	-
CBR tests after four days of soaking in water on constipated samples with humidity ±2% of the optimum at 99% of the maximum density of the modified Proctor test energy.	-	-	-	-	110%

4.3. CDW and EAF Mix Design Suitable as Road Subgrade

The road subgrades (both in embankments and in trenches) can be realized, in order of priority, with A1-a, A1-b, A2-4, A2-5 and A3 soil groups using a uniformity coefficient (D60/D10) greater than 7, if [28]:

- there are no granules with a diameter greater than 63 mm;
- the 0.063 mm passing is less than or equal to 15%;
- the plasticity index is less than or equal to 6;
- the 16 mm sieve passing is at least 50%;
- the CBR lift index is higher than 10% after 4 days of immersion in water.

The standard UNI 11531-1 [41] also prescribes that the CDW for these uses are characterized by an equivalent in sand greater than 30; that are in accordance with the leaching test (Table 1) and that the "Los Angeles" coefficient is less than 45 (Table 2). The mix-design employed contains 72% of B0/63, 23% of C0/4 and 5% of E0/31.5 aggregate. This mixture, belonging to the A1-a group, is part of the granulometric range provided by the regulations and allows one to satisfy both the main requirements imposed for road foundations and the leaching test (Tables 3 and 4 and Figure 3). It should be noted that the "Los Angeles" coefficient of the mixture is equal to 40 (value lower than the limit imposed by the legislation equal to 45) and this permits one to operate without EAF integrations, while the CBR lift index after four days of water imbibition was 65% [55]. Ultimately, the mixture obtained is suitable for use in the construction of road subgrades. A summary of the experimental results is given in Table 5.

4.4. CDW and EAF Mix Design Suitable as Road Foundation

The main performance requirements for CDW to be used as road foundations (Table 2) concern the sand equivalent (minimum value equal to 30), fragmentation resistance (coefficient "Los Angeles" less than 30) and compliance with the leaching test. It is observed that an extremely binding requirement is represented by the resistance to fragmentation [51]. This derives from the fact that road foundations are generally very stressed and therefore require a Los Angeles coefficient that is significantly lower than that of embankments and subgrades (Table 2). As consequence, to enhance the fragmentation resistance of the design mixture, it was decided to integrate it with a suitable quantity of granulated EAF slag (LA = 16). On these considerations, the chosen design mixture contained 52% of B0/63 aggregate, 18% of C0/4 aggregate, 20% of D4/8 and 10% of E0/31.5 (Tables 3 and 4 and Figure 4).

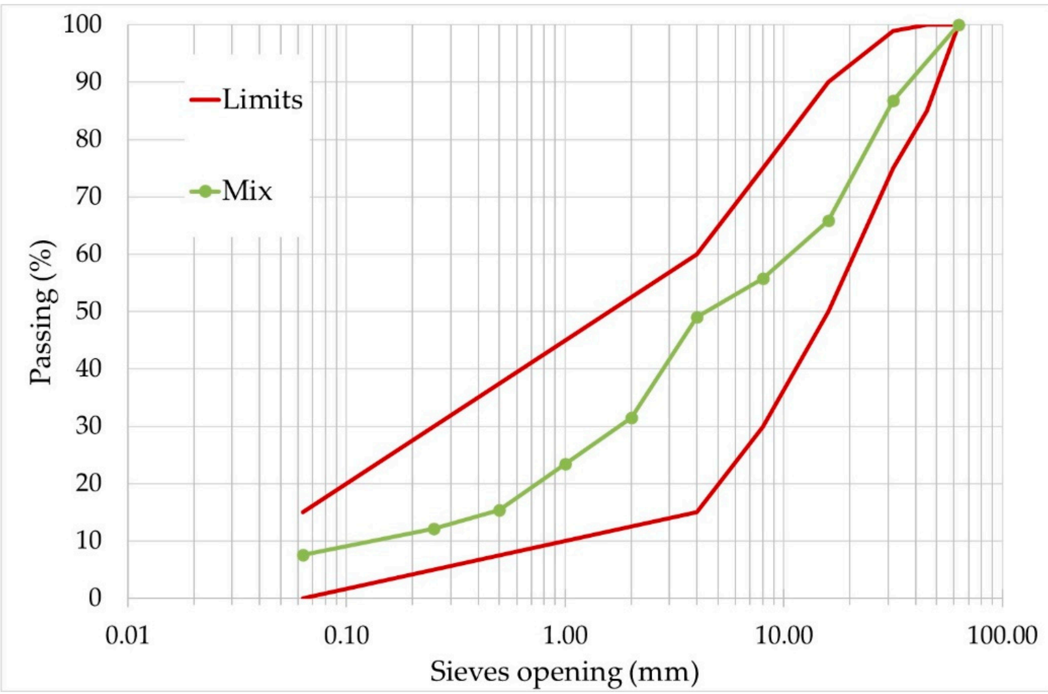

Figure 3. Particle size distribution and grading envelope 0/31.5 GU for road subgrades of CDW.

The presence of the granulated EAF slag considerably improves the fragmentation resistance of the design mixture, considering that its "Los Angeles" coefficient is equal to 28 (Table 5) and therefore, lower than the limit value required equal to 30 (Table 2).

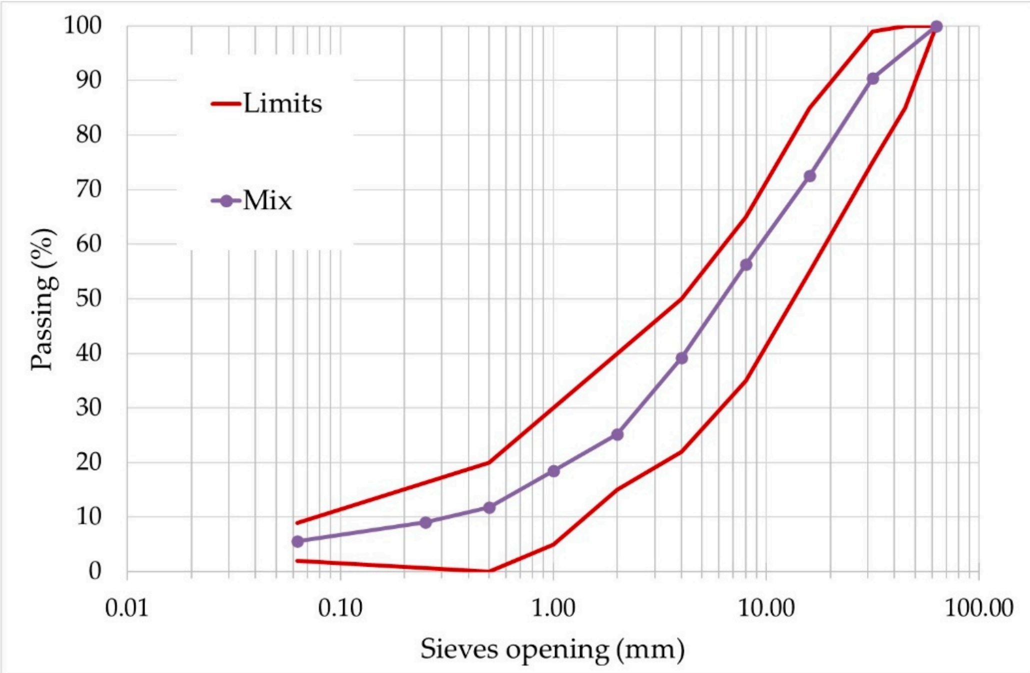

Figure 4. Particle size distribution and grading envelope 0/31.5 GA, for road foundations of CDW.

The mixture is also characterized by a sand equivalent value equal to 71 (Table 5), much greater than 30 that is the minimum required value (Table 2). The limitations related to compliance with the leaching test (Table 1), the flattening of the coarse aggregate and the CBR lift index after four days of water imbibition, are also largely verified (Tables 2 and 5). In general, the design mixture meets all the requirements established by current legislation, so it is suitable to be used as a road foundation (Table 5).

4.5. CDW and EAF Mix Design Suitable as Unbound Base

As already observed for foundations, also for the unbounded bases of road pavements, an important requirement asked by the current legislation [41] is represented by the resistance to fragmentation (Table 2). For this reason, also in this case, the designed mixture foresees a suitable quantity of EAF. Specifically, it is made up of 50% of B0/63, 10% of C0/4, 30% of D4/8 and 10% of E0/31.5 (Tables 3 and 4 and Figure 5).

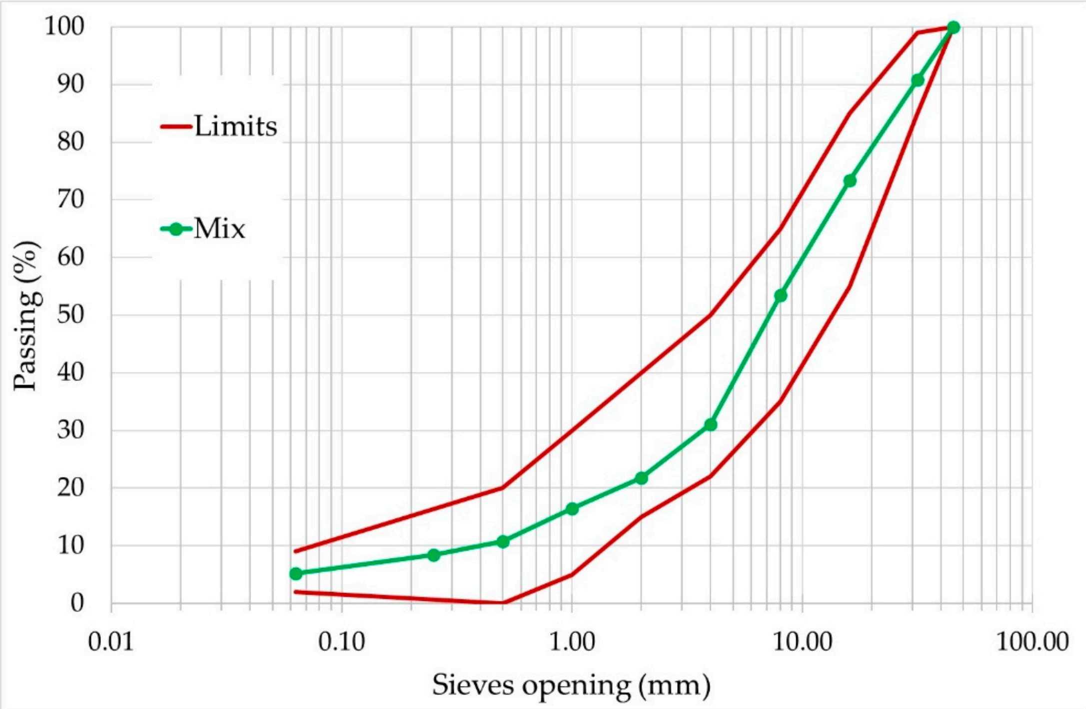

Figure 5. Particle size distribution and grading envelope 0/31.5 GA for unbound bases of CDW.

The presence of the granulated EAF slag guarantees a good resistance to fragmentation, considering that the "Los Angeles" coefficient of the designed mixture is equal to 25 and that this value is lower than the limit value of 30 (Tables 2 and 5).

Additionally, in this case, the limitations related to the leaching test (Table 1), to the sand equivalent, to the flattening of the coarse aggregate, to the CBR lift index after four days of water imbibition and to the percentage of crushed/rounded particles [58] are widely verified (Tables 2 and 5). For this reason, the designed mixture is suitable to be used as an unbound base layer.

5. Conclusions

The use of CDW in road construction brings significant advantages in environmental and landscape terms, because it allows both a reduction in the quantity of waste to be disposed of in landfills and the amount of virgin material to be taken from the loan quarries. In addition to the environmental advantage, this also entails an economic advantage, considering that the cost of landfill disposal is reduced.

This work has allowed one to demonstrate that the CDW is suitable for the construction of road embankments and subgrades, and in all those applications where incoherent materials are required, without clay and with a modest fragmentation resistance.

For unbounded layers, such as foundation layers and unbound bases, where a good fragmentation resistance is required, the use of CDW, as such, has revealed some limits. For this reason, it was decided to integrate the CDW with a granulate slag coming from Electric Arc Furnace (EAF) and/or with an additional CDW coming from the recovery of a concrete with slag.

One of the main aims of the study was to reduce to a minimum the additions of EAF because of its high cost. In order to reach this goal, the strictly necessary amount of EAF to report the values of the "Los Angeles" coefficient was used, just below the maximum limits set by the standard UNI 11531-1. Ultimately, this study has allowed us to design a series of suitable mixtures containing recycled materials, in compliance with current EN standards, to be used in the context of eco-compatible road constructions with low environmental impact.

Author Contributions: All authors contributed equally to the research and the writing of this manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors are grateful to Arch. M.A. Schirò Administrator of INECO s.r.l. (Barile, Potenza, Italy) for supplying the CDW and technical support in the preparation of the article.

Conflicts of Interest: The authors declare no conflict of interest.

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