CRABforOERE

Reclaimed asphalt aggregate characterisation for use in cold recycled material mixtures: testing procedures and acceptance ranges

Deliverable D3

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Deliverable D3 – Reclaimed asphalt aggregate characterisation for use in cold recycled material mixtures: testing procedures and acceptance ranges

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1. Introduction

1.1. Background

Cold recycling (CR) technologies are valid solutions for recycling a large amount of reclaimed asphalt (RA) aggregate obtained from the demolition of end-of-life bituminous pavements. Cold recycled materials (CRM) allow the re-use of a significant amount of RA aggregate, generally between 50% and 100% with less sensitivity regarding RA properties (Mollenhauer & Simnofske, 2015) compared to hot and warm recycling technologies.

In Europe, the qualification of RA aggregate is currently carried out according to EN 13108-8. This standard focuses on the reuse of RA in conventional hot mixtures. During hot (and warm) recycling, the aged bitumen contained in the RA is re-heated and re-activates, often with the help of rejuvenating or softening additives (LoPresti et al., 2020; Stimilli et al., 2015). A new binder, obtained from the blending of the re-activated aged bitumen and the new fresh bitumen, coats the aggregates, giving cohesion to the mixtures and affecting their mechanical properties.

Cold recycling is carried out at ambient temperature. If bitumen emulsion is used, the binder films that form upon emulsion breaking and setting, incorporate the fine particles forming a mortar that bounds the coarser RA aggregate. Similarly, when foamed bitumen is mixed, tiny bitumen particles and fines form a mastic that adheres to the surface of RA aggregate particles. In both cases the aged binder that covers the RA particles is solid and thus blending with fresh bitumen is practically impossible, especially in the case of emulsion.

Since the aged RA binder is much stiffer and less temperature-susceptible than the fresh binder, RA particles are often considered in the current practice, as “black rock”. This is clearly a simplification because the aged bitumen is still a time- and temperature dependent material, and therefore it may affect the rheological behaviour of CRM mixtures (Graziani et al., 2020). The European Standard for Asphalt Concrete with Bituminous Emulsion (EN 13108-31) confirms this uncertainty on the role of the aged binder by stating that the “binder in the reclaimed asphalt can be considered as active, partially active or inactive in the contribution to the properties of the mixture”. Dependent on the cohesion of the RA particles, the RA grading – rather than the grading of the aggregates within the RA – plays an important role within the mechanical performance of the CRM.

Considering that RA particles as a black rock, the aged bitumen affects the particle dimension, shape, resistance to fragmentation, water absorption and many other physical, mechanical, and chemical properties. Also, the aged binder that coats the aggregate particles affects their surface charge and thus their compatibility with the fresh bitumen, as well as breaking process of the bitumen emulsion.

1.2. Aims and Methodology

The objective of this deliverable report as the main output of CRABforOERE-work package 3 (WP3) was to propose a set of procedures and acceptance limits for characterising RA aggregate for CRM applications considering the. To facilitate the use of RA in CRM, it is natural to measure and declare its properties using the same approach currently adopted for aggregates in other paving mixtures.

The present document reviewed and compared national/local specifications for aggregates to be used in hot and cold bituminous mixtures. Based on this review, a basic set of “consensus properties” was established among the properties required throughout Europe. The performance levels adopted for quality control or acceptance testing were also evaluated. The standards EN 13043 and EN 13242 were used as a guide for preparing a set of summary tables.

Afterwards, nine different RA aggregate samples produced in different European countries were collected and characterised measuring the aforementioned “consensus properties”. Also, the different properties were compared to assess the existence of mutual relationships.

Based on the outcomes of the specifications review and the characterisation or RA sources, recommendations for RA aggregate for being used in CRAB mixtures were proposed.

1.3. List of Abbreviations

UM	Unbound Materials (for subbase courses)
HBM	Hydraulically Bound Mixtures (for base and subbase courses)
CBSM	Cement-Bitumen Stabilised materials (for base and subbase courses)
ACBE	Asphalt Concrete with Bitumen Emulsion (for base courses)
GE	Grave emulsion
BM	(Hot) Bituminous Mixtures (for base courses)
CRBM	Cold Recycled Bound Materials (for base, subbase and binder courses, include HBM, CBSM and ACBE)
TBD	To Be Determined
NP	Not Present
NR	No requirement
ADT	Average daily traffic (of heavy-duty vehicles)

2. Review of Specifications

National documents were collected by the Partners and analysed to define the specifications required for aggregate. Table 1 lists the eight National documents considered.

Two Italian specifications were considered, the "*Capitolato Provincia autonoma di Bolzano – Alto Adige"*; and the "*Capitolato Autostrade per l'Italia"*. In each specification, the requirements for the aggregate are defined as a function of the type of mixture/layer.

The main German document considered was the "*Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflächenbestingungen* (TL - Asphalt – StB)". The document collects the specifications for hot bituminous mixtures as a function of the traffic level. The Annex A, focusing on the properties and categories of aggregates for asphalt, refers to TL - Gestein – StB04 (*Technische Lieferbedingungen für Gesteinskörnungen im Straßenbau*). In the document M VB – K (*Merkblatt für die Verwertung von pechhaltigen Straßenausbaustoffen und von Asphaltgranulat in bitumengenbundendenen Tragschichten durch Kaltaufbereitung in Mischanlagen*), which regulates the preparation of cold mixtures, there are no specific indications regarding the aggregate, but the aggregate must meet the technical delivery conditions specified in TL - Gestein – StB04.

For the United Kingdom, the document considered is the "*Manual of contract documents for highway works, volume 1 specification for highway works*". In the document the aggregate requirements refer to bituminous mixtures in general. For some of the requirements the manual refers to the BSI PD 6691 (Guidance on the use of BS EN 13108). For cold materials the specification collects the requirements for mixtures for "base and binder courses produced in a fixed or mobile mixing plant […] blended if necessary with other aggregate and bound with cementitious, hydraulic or bituminous binders, separately or in combination". Thus, the section analysed can be applied for both hydraulically bound mixtures and cement-bitumen stabilised materials.

In France, the standard "*NF P 98-121* (*Assises de chaussées - Grave-émulsion - Définition - Classification - Caractéristiques - Fabrication - Mise en oeuvre*)" regulates the requirements for aggregates for cold mixtures with bitumen emulsion (not hydraulically bounded). The requirements for UM, HBM ad BM are listed in the document "*Aide au choix des granulats pour chaussées basée sur les normes européennes*" published by the Institut Des Routes, des Rues et des Infrastructures pour la Mobilité.

Two Sweden specifications were analysed "*TDOK 2013:0529 Bitumenbundna lager" and "TDOK 2013:0530 Obundna lager för vägkonstruktioner",* specifying national requirements for bound and unbound materials, respectively. Listed specification for CRM are valid only for low traffic road (ADT≤1500). For roads with higher traffic volumes, it is expressed that a special investigation is needed before applying CRM. According to the National Road Authority (NRA), it may be generally expressed that a CRM should formed such that the performance is equally good, or better, as that of a conventional HMA.

Table 2 lists the analysed specifications for each document. The specifications consider aggregates meant to be used in various pavement subbase and base courses. Also, different types of materials were considered, from unbound materials to asphalt concrete and CR materials.

Table 1: List of national/local documents

ID	Document	Country
CSA1	Capitolato provincia autonoma di Bolzano	ITA
CSA2	Capitolato Autostrade per l'Italia	ITA
TLA	TL - Asphalt – StB - Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflachenbestingungen	DE
MCHW1	Manual of contract documents for highway works volume 1 specification for highway works	UK
NFGE	NF P 98-150-2 - Assises de chaussées - Grave-émulsion - Définition - Classification - Caractéristiques - Fabrication - Mise en oeuvre	FR
IDRRIM	Aide au choix des granulats pour chaussées basée sur les normes européennes (Institut Des Routes, des Rues et des Infrastructures pour la Mobilité)	FR
TDOK	TDOK 2013:0529 Bitumenbundna lager	SE
TDOK	TDOK 2013:0530 Obundna lager för vägkonstruktioner	SE

Table 2: List of analysed specifications

ID	Country	Course	Specification
CSA1_UM	ITA	Subbase	Misto granulare
CSA1_HBM	ITA	Subbase Base	Misto cementato
CSA1_CSBM	ITA	Subbase	Fondazione stabilizzata con cemento ed emulsione bituminosa sovrastabilizzata
CSA1_ACBE	ITA	Base	Conglomerati bituminosi riciclati a freddo per la formazione di strati di base
CSA1_BM	ITA	Base	Base a caldo con bitume modificato
CSA2_UM	ITA	Subbase	Misto granulare non legato per fondazione
CSA2_HBM	ITA	Subbase	Fondazione in misto cementato confezionato in centrale
CSA2_CSBM	ITA	Subbase Base	Fondazioni legate
CSA2_BM	ITA	Base	Conglomerati bituminosi a caldo per strati di base
TLA_BM	DE	Base	TL - Asphalt
MCHW1_CRBM	UK	Base	Aggregates for bituminous mixtures-Ex situ cold recycled bound material
MCHW1_BM	UK	Base	Aggregates for bituminous mixtures-Dense base
NFGE_GE	FR	Base	Grave emulsion
IDRRIM_UM	FR	Subbase Base	Grave non traitée
IDRRIM_HBM	FR	Subbase Base	Grave traitée aux liants hydrauliques
IDRRIM_BM	FR	Subbase Base	Enrobés bitumineux
TDOK 2013:0529	SWE	Bound layers	Bitumenbundna lager
TDOK 2013:0530	SWE	Base/ subbase	Obundna lager för vägkonstrruktioner

2.1. List of requirements

The review of the National documents allowed defining a list of requirements for aggregates to employ for producing the following materials:

1. unbound materials (UM) and hydraulically bound materials (HBM) (Table 3),
2. CRM mixtures (Table 4),
3. bituminous (hot) mixtures (Table 5).

Annex A reports the list of the aggregate requirements.

Table 3: Summary of requirements for unbound materials and hydraulically bound materials

Requirement	Testing standard	CSA1 UM	CSA2 UM	IDRRIM UM	CSA1 HBM	CSA2 HBM	IDRRIM HBM
Upper aggregate size (mm)	EN 933-1	X	X	-	X	X	-
Maximum value of fines content (%)	EN 933-1	-	-	X	X	-	X
Flakiness index (%)	EN 933-3	X	-	X	X	-	X
Shape Index (%)	EN 933-4	X	-	-	X	-	-
Crushed aggregate particle (%)	EN 933-5	X	X	X	X	X	X
Totally rounded particle (%)	EN 933-5	X	-	X	X	-	X
Angularity of fine aggregates	EN 933-6	-	-	X	-	-	X
Sand Equivalent (%)	EN 933-8	X	X	X	X	X	X
Methylene blue	EN 933-9	-	-	X	X	-	X
Resistance to fragmentation (Los Angeles) (%)	EN 1097-2	X	X	X	X	X	X
Resistance to fragmentation (Impact test) (%)	EN 1097-2	X	-	-	X	-	-
Resistance to wear (micro-Deval)	EN 1097-1	-	-	X	-	-	X
Magnesium sulphate test (%)	EN 1367-2	-	-	-	X	-	-
Resistance to freezing and thawing (%)	EN 1367-1	X	-	-	X	-	-
Limit Liquid (%)	CEN ISO/TS 17892-12	X	-	-	X	-	-
Plasticity index	CEN ISO/TS 17892-12	X	-	-	X	X	-
Water Absorption (%)	EN 1097-6	-	-	-	X	-	-
Organic substance (%)	EN 1744-1	-	-	-	-	-	-
Water soluble components (%)	EN 1744-3	-	-	-	-	-	-
California Bearing Ratio (%)	EN 13286-47	-	X	-	-	-	-
Soundness (%)	BS 812-121	-	-	-	-	-	-

Table 4: Summary of requirements for cold recycled mixtures (bounded with bitumen and eventually hydraulic binder)

Requirement	Testing standard	CSA1 CSBM	CSA1 ACBE	CSA2 CSBM	MCHW1 CRBM[(b)]	NFGE GE
Upper aggregate size (mm)	EN 933-1	X	X	X	X	-
Maximum value of fines content (%)	EN 933-1	X	X	-	X	X
Flakiness index (%)	EN 933-3	X	X	-	-	X
Shape Index (%)	EN 933-4	-	-	-	-	-
Crushed aggregate particle (%)	EN 933-5	X	X	X	-	X
Totally rounded particle (%)	EN 933-5	X	X	X	-	X
Angularity of fine aggregates	EN 933-6	-	-	-	-	X
Sand Equivalent (%)	EN 933-8	X	X	-	-	X
Methylene blue	EN 933-9	-	-	-	-	X
Resistance to fragmentation (Los Angeles) (%)	EN 1097-2	X	X	-	X	X
Resistance to fragmentation (Impact test) (%)	EN 1097-2	-	-	-	-	-
Resistance to wear (micro-Deval)	EN 1097-1	-	-	-	-	X
Magnesium sulphate test (%)	EN 1367-2	-	-	-	X	-
Resistance to freezing and thawing (%)	EN 1367-1	X	X	-	X	-
Limit Liquid (%)	CEN ISO/TS 17892-12	X	X	-	-	-
Plasticity index	CEN ISO/TS 17892-12	X	X	X	-	-
Water Absorption (%)	EN 1097-6	X	X	-	X	-
Organic substance (%)	EN 1744-1	-	-	-	-	-
Water soluble components (%)	EN 1744-3	-	-	-	-	-
California Bearing Ratio (%)	EN 13286-47	-	-	-	-	-
Soundness (%)	BS 812-121	-	-	-	X	-

[(b)] CRBM comprises hydraulically bound mixtures and cement-bitumen stabilised materials.

Table 5: Summary of requirements for (hot) bituminous mixtures

Requirement	Testing standard	CSA1 BM	CSA1 BM	TLA BM	MCHW1 BM	IDRRIM BM
Upper aggregate size (mm)	EN 933-1	X	X	X	X	-
Maximum value of fines content (%)	EN 933-1	X	-	X	X	X
Flakiness index (%)	EN 933-3	X	X	X	X	X
Shape Index (%)	EN 933-4	-	X	X	-	-
Crushed aggregate particle (%)	EN 933-5	X	X	X	-	X
Totally rounded particle (%)	EN 933-5	X	-	X	-	X
Angularity of fine aggregates	EN 933-6	-	-	X	-	X
Sand Equivalent (%)	EN 933-8	X	X	-	-	X
Methylene blue	EN 933-9	-	-	-	-	X
Resistance to fragmentation (Los Angeles) (%)	EN 1097-2	X	X	X	X	X
Resistance to fragmentation (Impact test) (%)	EN 1097-2	-	-	-	-	-
Resistance to wear (micro-Deval)	EN 1097-1	-	-	-	-	X
Magnesium sulphate test (%)	EN 1367-2	-	-	-	X	-
Resistance to freezing and thawing (%)	EN 1367-1	X	X	X	X	-
Limit Liquid (%)	CEN ISO/TS 17892-12	-	-	-	-	-
Plasticity index	CEN ISO/TS 17892-12	-	X	-	-	-
Water Absorption (%)	EN 1097-6	X	X	X	X	-
Organic substance (%)	EN 1744-1	-	-	X	-	-
Water soluble components (%)	EN 1744-3	-	-	-	-	-
California Bearing Ratio (%)	EN 13286-47	-	-	-	-	-
Soundness (%)	BS 812-121	-	-	-	X	-

Besides the requirements listed in EN 13043 and EN 13242, additional tests may be useful for identifying RA aggregate to be used in CRM:

1. The rise in pH test, mainly adopted in France, evaluates compatibility between RA and bitumen emulsion (Ziyani et al., 2014);
2. The XRD test evaluates the mineralogy of the aggregate and helps in assessing its compatibility with bitumen emulsion;
3. The Fragmentation test, developed within RILEM TC 237-SIB, evaluates RA stability under compaction (Perraton et al., 2016). The test was introduced to allow a rapid characterization of the RA aggregate used in the field in an amount of time compatible with the times of construction work plan;
4. The soluble binder content may help in estimate the influence of the aged binder on the mechanical response of CRM mixtures (EN 12697-1).

2.2. List of Consensus Properties

Based on the properties required by the different National documents, a list of consensus properties was established (Table 6). The properties were selected because they are present in most of the examined documents and therefore their measurement is deemed useful for selecting RA aggregate for CRM mixtures.

Table 6. List of consensus properties proposed

Requirement	Reference
Upper aggregate size (mm)	EN 933-1
Maximum value of fines content	EN 933-1
Flakiness index	EN 933-3
Shape Index	EN 933-4
Crushed aggregate particles	EN 933-5
Sand Equivalent	EN 933-8
Resistance to fragmentation (Los Angeles)	EN 1097-2
Resistance to freezing and thawing	EN 1367-1
Water Absorption	EN 1097-6
Limit Liquid	UNI CEN ISO/TS 17892-12
Plasticity index	UNI CEN ISO/TS 17892-12
Rise in pH	Ziyani et al., 2014
Fragmentation	Perraton et al., 2016
Soluble binder content	EN 12697-1

3. Reclaimed Asphalt Aggregate Qualification

3.1. Materials

The list of consensus properties was adopted for qualifying different RA aggregate produced in Europe. In particular, nine samples RA-samples were considered (Table 7 and Figure 1).

The RA aggregate sample UK_1, coming from the United Kingdom, was provided in two fractions (coarse and fine) and therefore the relevant fraction was used for testing, e.g. the Los Angeles test was carried out on the coarse fraction whereas the sand equivalent test on the fine fraction. When both fractions were tested, they were distinguished using the codes UK_1-C and UK_2-F for the coarse and the fine aggregate, respectively.

Table 7. List of RA samples considered

ID	Country of production
ITA_1	Italy
ITA_2	Italy
GER_1	Germany
GER_2	Germany
UK_1	United Kingdom
UK_2	United Kingdom
SWE_1	Sweden
SWE_2	Sweden
FRA_1	France

3.2. Methods

The aggregates were characterised following the European standards for natural aggregate. The only caution was the use of a lower temperature for the oven-drying operations. The temperature of 40 °C was adopted, instead of 110 °C, to avoid altering the RA aggregate properties due to the softening of the aged bitumen. When needed, the all-in RA aggregate was subjected to laboratory sieving for obtaining fractions consistent with the testing requirements.

The Los Angeles and Fragmentation test were carried out in the coarser fraction of the materials. Specifically, the Los Angeles test is usually performed on the material fraction 10/14 on a reconstructed sample comprising between 60% and 70% of material passing a 12.5 mm sieve. However, additional grading requirements allow the test sample to be created from product sizes other than 10/14 (EN 1097-2, Table B.1). Thus, different RA aggregate fractions were adopted when the aggregate was poor of the 10/14 fraction. Some RA samples were tested considering more than one fraction. Table 8 lists the testing fractions considered for each RA source.

Table 8. Tests fractions considered within the study for the fragmentations tests and the freezing and thawing test.

ID	Fragmentation tests	Freezing and thawing test
ITA_1	10/14 – 4/10 – 4/16	10/14
ITA_2	10/14	10/14
GER_1	6.3/10	6.3/10
GER_2	6.3/10	6.3/10
UK_1	10/14 – 6.3/10	6.3/10
UK_2	6.3/10	6.3/10
SWE_1	4/8	4/8
SWE_2	4/8	4/8
FRA_1	6.3/10	6.3/10

The fragmentation test was carried out following the procedure developed within the RILEM TC 237-SIB (Perraton et al., 2016). It was developed considering four fractions 5/10, 10/14, 14/20, 20/30. However, in this study, the test was carried out on the same fraction selected for the Los Angeles tests and the samples were obtained using the same procedure used for the Los Angeles test.

Each fragmentation test sample weighed about 4000 g. The test was performed on aggregate conditioned for at least 4 hours at 20 °C. The fragmentation test consists in carrying out a Modified Proctor test (AASHTO T180) on the loose aggregate: 5 layers of the approximately same thickness are placed in the Proctor mould. Each layer is compacted as required for the Modified Proctor procedure, i.e. 56 blows, 4.5 kg rammer, 457 mm height of fall. The collar and the excess material are then removed, and the mass of material in the mould M_1; is determined. It is sieved at the 1.6 mm sieve to remove the finest particles produced during fragmentation. After that, M_2 is obtained, corresponding to the mass of the retained material after sieving. The fragmentation resistance of RA aggregate is evaluated in terms of Passing Control Sieve (PCS) as follows:

$$PCS = \frac{M_1 - M_2}{M_1} \cdot 100$$

The rise in pH test, used for assessing the chemical reactivity of aggregate in aqueous solution at ambient temperature was carried out according to the protocol designed by the French Regional Laboratory of Saint-Brieuc (Odie et al., 2011). The reactivity test consists in measuring the evolution of the pH of an acidified aqueous phase solution (300 ml) of a bitumen emulsion brought into contact with the granular mixture (60 gr). The pH of the aqueous solution was measured at different times, ranging from 0 to 4000 s. The reactivity, which results in an increase in pH, is linked to the consumption of hydronium ions (linked to the use of hydrochloric acid for example) by the mineral elements extracted from the granular surface. A rise in pH, making it possible to reach a final value greater than or equal to 6, will lead to the cationic emulsion breaking. The rise in pH test was carried out on:

- the nine RA aggregate samples (Table 7);
- the nine extracted RA aggregate to assess the capacity of the bitumen to influence the kinetics of the rise in pH.

Besides, in order to establish the link of this physico-chemical test with the mechanical performance of mixtures incorporating cement in their composition and formulation, a specific investigation was carried out on the RA GER1. The effect of the dosage (by mass) of cement (0, 1 and 3%) in the RA mixture after binder extraction was evaluated. The obtained results were further compared with the results obtained by adding to the acid aqueous phase only cement (1%) without any additional aggregates or RA. Finally, to compare the reactivity obtained using the aqueous solution and the emulsion, RA aggregate ITA1 extracted was tested also in a cationic emulsion from Italy.

Additionally, X-ray crystallography (X-ray diffraction XRD) tests were carried out at the aggregates extracted from the fine RA fraction used also in the rise in pH test.

Resistance to freezing and thawing was measured in terms of strength loss carrying out the Los Angeles test on aggregates subjected to the freeze-thaw cycling (EN 1097-2, Annex B). Table 8 lists the testing fraction considered.

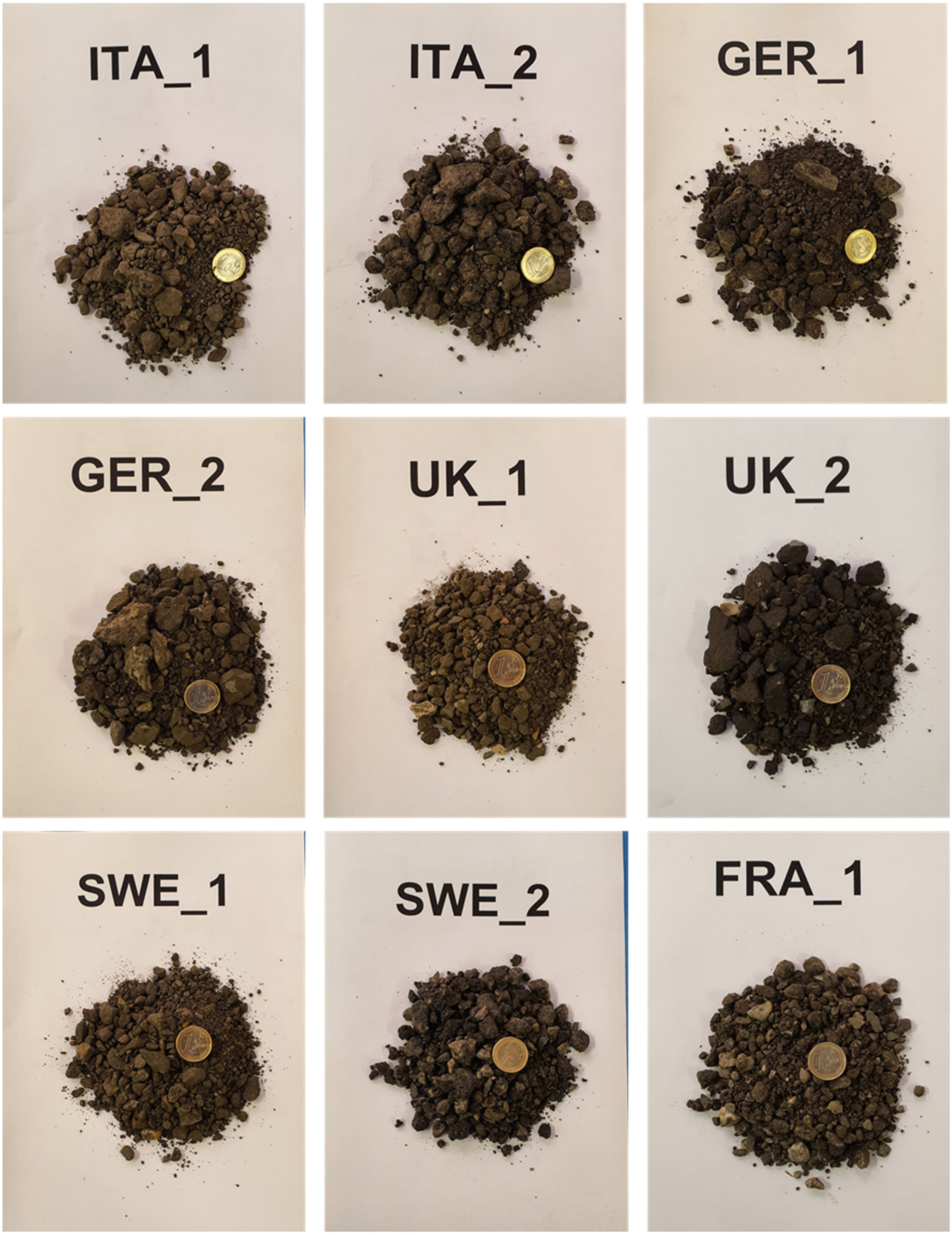


Figure 1. RA samples characterised

3.3. Results

This section summarises the results obtained by measuring the consensus properties of the nine RA sources. If present, the limits proposed by the relevant National specifications are reported, together with the results.

3.3.1. Soluble Binder Content

Figure 2 shows the soluble binder content (B) of the different RA aggregates. As expected, results showed a high variability, with values between 3.1 and 6.5%, and an average of about 5%. The lowest value, 3.1% refers to UK_1-coarse fraction sample and may be due to the low amount of sand fines fractions.

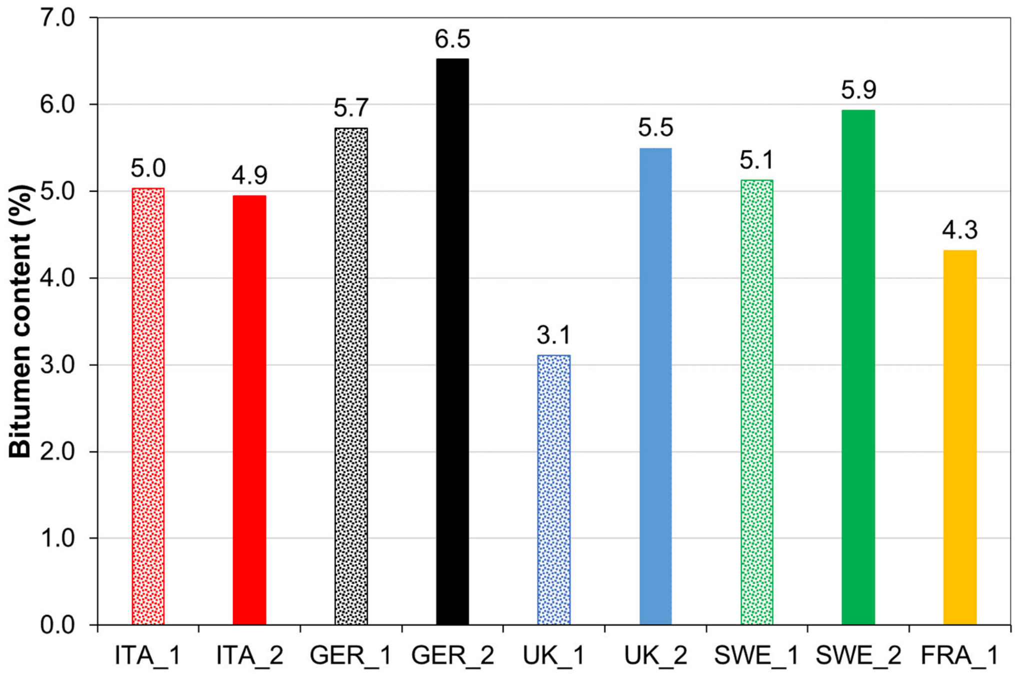


Figure 2. Soluble binder content of the RA aggregate samples characterised

3.3.2. Grading

Figure 3 shows the grading distributions of the nine aggregate sources, and the grading curves corresponding to the maximum density (Fuller-Thompson curve) for the maximum dimensions 14 and 45 mm. All RA samples were poor of fine particles (passing to 4 mm) and fines (passing to 0.063 mm). This means that in CRM mixtures design, the addition of virgin aggregate fines is necessary if a distribution close to the maximum density is required.

Figure 4 shows the maximum dimension and the fines content of the nine RA sources. The maximum dimension was 16 mm or 12 mm, making them suitable for being used both in base and binder courses (Figure 4a). The fines content was extremely variable. However, most RA samples had fines content lower than 1%, with the only exception of ITA_1 and SWE_2, having fines contents equal to 5.6% and 2.5%, respectively (Figure 4b). It must be highlighted that the high fines content of ITA_1 can be due to the crushing process that was carried out at the plant before stockpiling. Therefore, processing the RA with an initial crushing could be helpful for increasing the quantity of fines and reducing the natural aggregate addition needed for achieving the grading requirements of CRM.

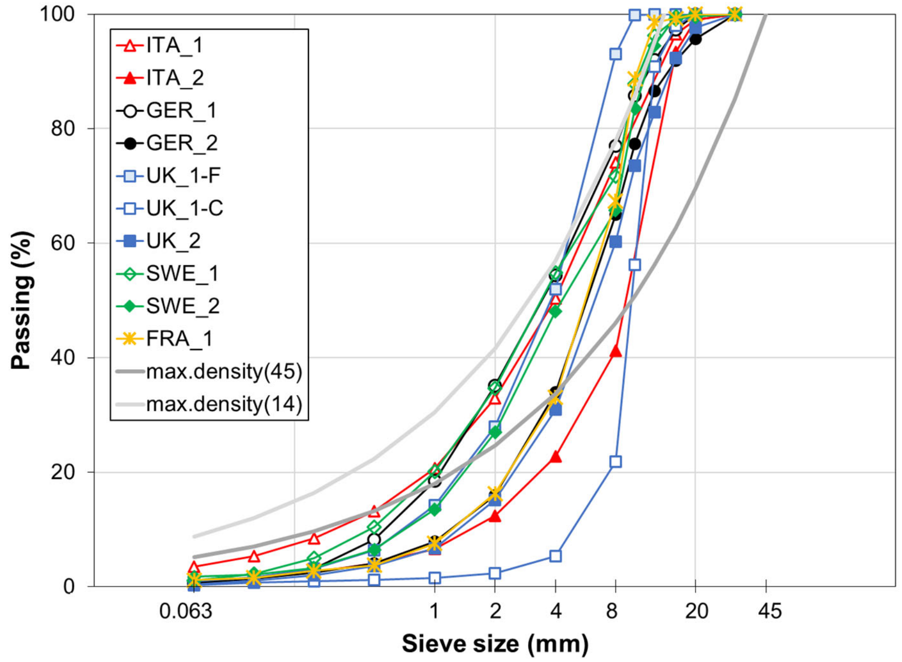


Figure 3. Grading distribution of the RA aggregate samples characterised

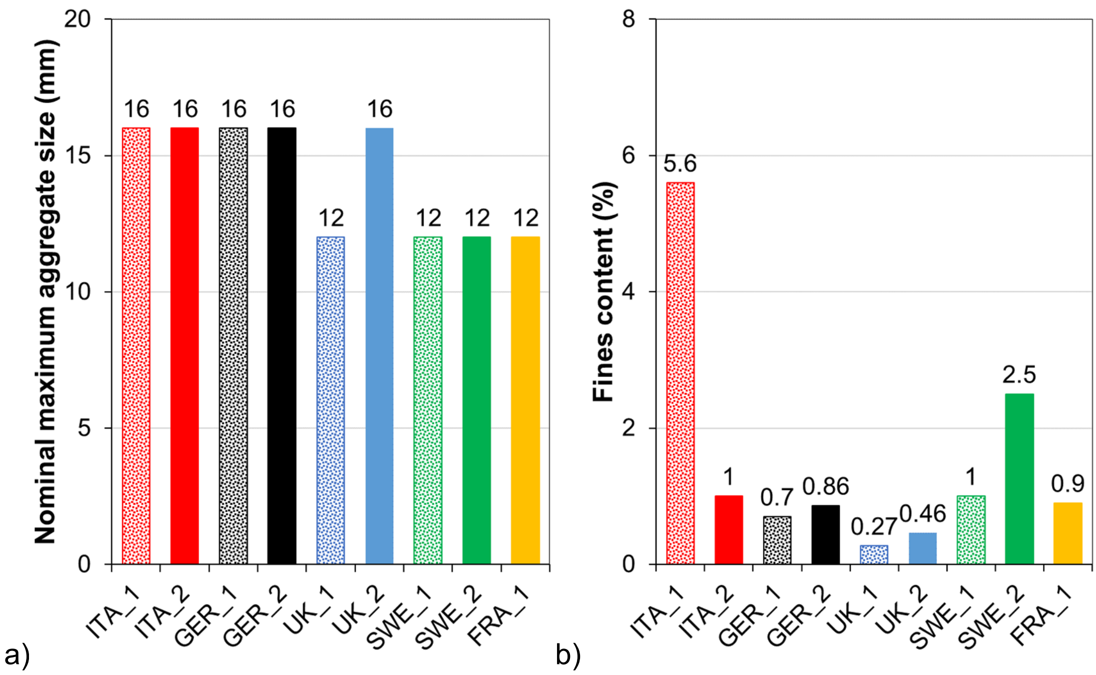


Figure 4. Geometrical properties of RA aggregate samples a) nominal maximum aggregate size, b) fines content (passing 0.063 mm sieve)

Table 9 reports the RA designation obtained according to EN13043, EN 13242 and EN13108 - 8.

Table 10 reports the categories for the fines content of the nine RA sources, according to EN 13043 and EN 13242. All RA sources, except ITA_2, were included in the lowest category (i.e. f_3).

Table 9. Designation of the RA samples according to EN13043, EN 13242 and EN13108-8

ID	EN13043	EN 13242	EN13108-8
ITA_1	A 0/16 GA90	0/16 GA80	22 RA 0/10
ITA_2	A 0/16 GA90	0/16 GA80	22 RA 0/12
GER_1	A 0/16 GA90	0/16 GA80	20 RA 0/12
GER_2	A 0/16 GA90	0/20 GA85	24 RA 0/10
UK_1	A 0/12 GA90 and A 0/8 GA90	0/16 GA85 and 0/8 GA80	20 RA 0/10 and 12 RA 0/10
UK_2	A 0/16 GA90	0/16 GA80	24 RA 0/16
SWE_1	A 0/12 GA90	0/16 GA80	22 RA 0/10
SWE_2	A 0/12 GA90	0/12 GA80	16 RA 0/10
FRA_1	A 0/12 GA90	0/12 GA80	20 RA 0/10

Table 10. - Categories for fines content of RA according to EN 13043 and EN 13242

ID	EN13043	EN 13242
ITA_1	f_7	f_7
ITA_2	f_3	f_3
GER_1	f_3	f_3
GER_2	f_3	f_3
UK_1	f_3	f_3
UK_2	f_3	f_3
SWE_1	f_3	f_3
SWE_2	f_3	f_3
FRA_1	f_3	f_3

3.3.3. Flakiness Index and Shape Index

Figure 5 shows the values of the Flakiness index (FI) and the Shape Index (SI) of the nine RA samples. The FI ranged between 3.7% and 10.2%, whereas, the SI ranged between 2.6% and 16.9%. All the values of FI and SI were well below the upper limits required by the different National specifications.

Table 11 reports the categories for the FI of the nine RA samples considered according to EN 13043 and EN 13242. According to EN 13043, all nine RA samples can be classified in the lowest category, i.e. FI_{10}, except GER_2 which falls within the second category (FI_{15}). According to EN 13242 all nine RA samples can be classified in the lowest category, i.e. FI_{20}.

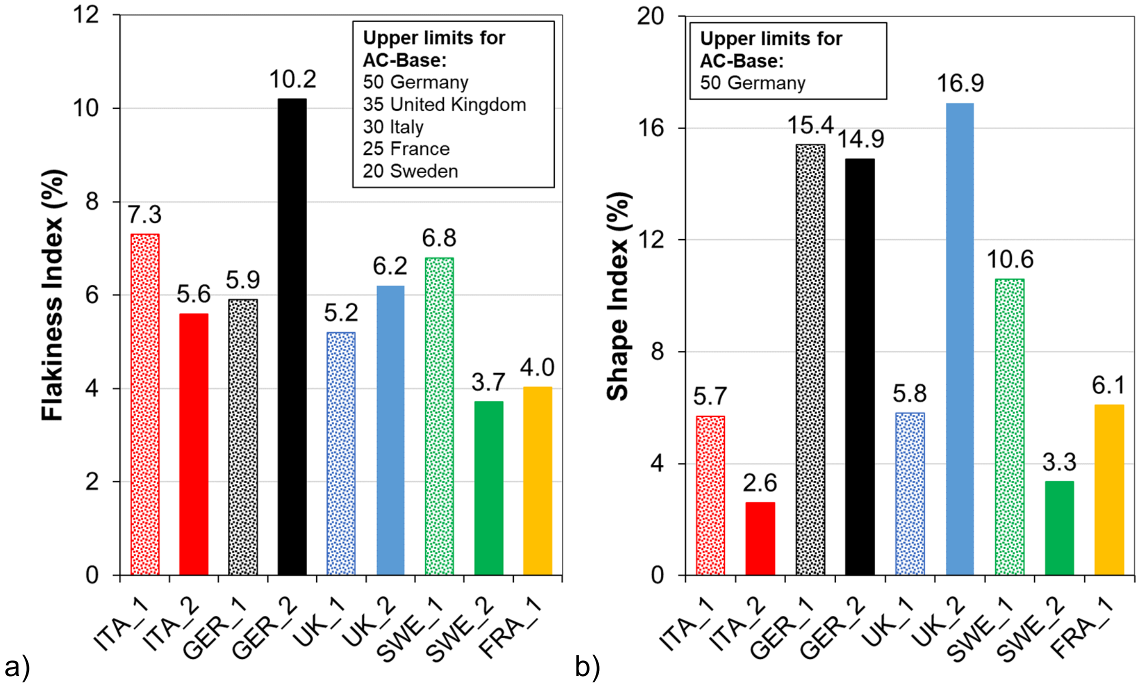


Figure 5. Geometrical properties of RA aggregate samples a) flakiness index, b) shape index

Table 11. - Categories for flakiness index of RA according to EN 13043 and EN 13242

ID	EN13043	EN 13242
ITA_1	FI_{10}	FI_{20}
ITA_2	FI_{10}	FI_{20}
GER_1	FI_{10}	FI_{20}
GER_2	FI_{15}	FI_{15}
UK_1	FI_{10}	FI_{20}
UK_2	FI_{10}	FI_{20}
SWE_1	FI_{10}	FI_{20}
SWE_2	FI_{10}	FI_{20}
FRA_1	FI_{10}	FI_{20}

Table 12 reports the categories declared for the SI of the nine RA considered according to EN 13043 and EN 13242. According to EN 13043, all nine RA aggregate can be classified in the two lowest categories, i.e. SI_{15} and SI_{20}. Differently all RA samples fall within the lowest category (SI_{20}) according to EN 13242.

Table 12. - Categories for shape index of RA according to EN 13043 and EN 13242

ID	EN13043	EN 13242
ITA_1	SI_{15}	SI_{20}
ITA_2	SI_{15}	SI_{20}
GER_1	SI_{20}	SI_{20}
GER_2	SI_{15}	SI_{20}
UK_1	SI_{15}	SI_{20}
UK_2	SI_{20}	SI_{20}
SWE_1	SI_{15}	SI_{20}
SWE_2	SI_{15}	SI_{20}
FRA_1	SI_{15}	SI_{20}

3.3.4. Crushed Aggregate Particles

All the nine RA samples have 100% of crushed particles in coarse aggregate, due to the production process of the RA aggregate.

Table 13 reports the categories declared for the crushed particles in coarse aggregate of the nine RA considered according to EN 13043 and EN 13242. All the samples fall into the maximum categories.

Table 13. - Categories for percentage of crushed particles of RA according to EN 13043 and EN 13242

ID	EN13043	EN 13242
ITA_1	$C_{100/0}$	$C_{90/3}$
ITA_2	$C_{100/0}$	$C_{90/3}$
GER_1	$C_{100/0}$	$C_{90/3}$
GER_2	$C_{100/0}$	$C_{90/3}$
UK_1	$C_{100/0}$	$C_{90/3}$
UK_2	$C_{100/0}$	$C_{90/3}$
SWE_1	$C_{100/0}$	$C_{90/3}$
SWE_2	$C_{100/0}$	$C_{90/3}$
FRA_1	$C_{100/0}$	$C_{90/3}$

3.3.5. Sand Equivalent

Figure 6 shows the Sand Equivalent (SE) values of the nine RA samples. The two Swedish samples and the French one had the highest values of SE, 90% or higher. The SE values of the Italian and UK_1 aggregates were about 70%. UK_2 and German RA aggregates had the lowest values, slightly above 50%. UK_2, GER_1 and GER_2 do not comply with the Italian specification limits for AC bases.

The variability of SE values that characterises some RA samples could be related to different storage type and time. For having a RA aggregate with good characteristics in terms of fines quality it is strongly recommended to pay attention on its storage.

Table 14 lists the categories declared for SE values of the nine RA samples considered according to EN 13043. All the RA are classified within the four highest categories. Standard EN 13242 does not define categories for the quality of fines.

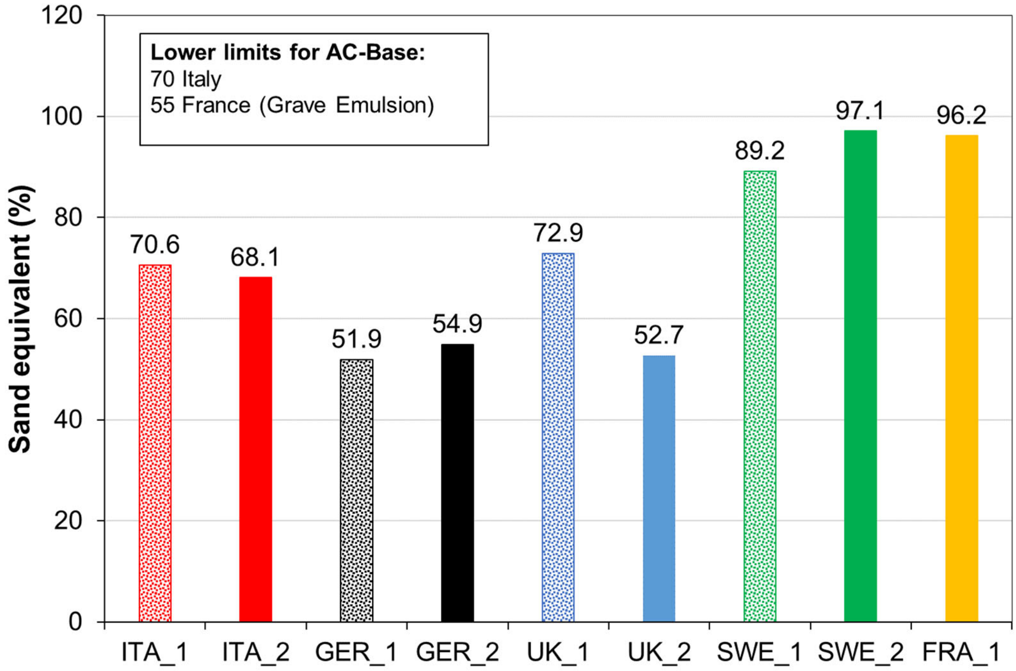


Figure 6. Geometrical properties of RA aggregate sources: sand equivalent

Table 14. - Categories for sand equivalent of RA according to EN 13043

ID	EN13043
ITA_1	$SE10_{65\ Declared}$
ITA_2	$SE10_{65\ Declared}$
GER_1	$SE10_{50}$
GER_2	$SE10_{50}$
UK_1	$SE10_{65\ Declared}$
UK_2	$SE10_{50}$
SWE_1	$SE10_{65\ Declared}$
SWE_2	$SE10_{65\ Declared}$
FRA_1	$SE10_{65\ Declared}$

3.3.6. Resistance to Fragmentation (Los Angeles)

Figure 7 shows the resistance to fragmentation of the different RA samples in terms of Los Angeles coefficient (LA). The values depicted for the ITA_1 and UK_1 refer to the 10/14 fraction (Table 8). All the aggregates tested showed LA values comprised between 15.7% and

17.2%, well below the upper limits required by the National Specifications, highlighting good characteristics in terms of resistance to fragmentation.

Table 15 reports the categories declared for the Los Angeles coefficient of the nine RA aggregates considered, according to EN 13043 and EN 13242. All the samples fall into the lowest categories, i.e. LA_{15} or LA_{20} according to EN 13043 and LA_{20} according to EN 13242.

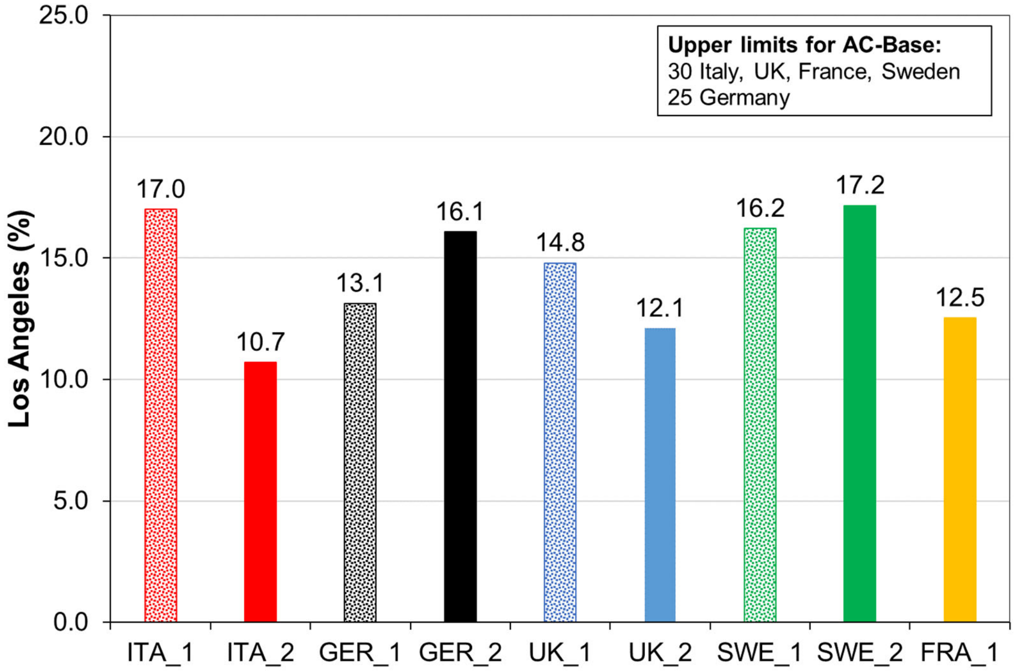


Figure 7. Mechanical properties of RA aggregate samples: Los Angeles coefficient

Table 15. - Categories for Los Angeles coefficient of RA according to EN 13043 and EN 13242

ID	EN13043	EN 13242
ITA_1	LA_{20}	LA_{20}
ITA_2	LA_{15}	LA_{20}
GER_1	LA_{15}	LA_{20}
GER_2	LA_{20}	LA_{20}
UK_1	LA_{15}	LA_{20}
UK_2	LA_{15}	LA_{20}
SWE_1	LA_{20}	LA_{20}
SWE_2	LA_{20}	LA_{20}
FRA_1	LA_{15}	LA_{20}

3.3.7. Water absorption

Figure 8 shows the water absorption (WA_{24}) of the nine RA samples investigated. All the aggregates had WA_{24} ranging between 1.1% and 2.1%. These values were always higher than the upper limits proposed by the German specifications (i.e. 0.5%), and close to the Italian and

UK limits, 1.5% and 2.0% respectively.

Table 16 reports the categories for WA_{24} values of the nine RA samples according to EN 13043. The aggregate GER_1 did not fall within any of the categories. According to the Standard, WA_{24} is a screening test for freeze-thaw resistance. Specifically, when $WA_{24} < 2\%$ the aggregate shall be assumed freeze-thaw resistant. Therefore, resistance to freezing and thawing should be determined only for GER_1.

It must be pointed out that CRM are generally produced adding water to help the workability and compactability. Thus, the non-compliance with the limits is not critical if it does not affect the freezing and thawing resistance. However, the correct definition and the declaration of WA_{24} of RA aggregate is crucial for having full control on the total water added to CRM and consequently on the volumetric properties.

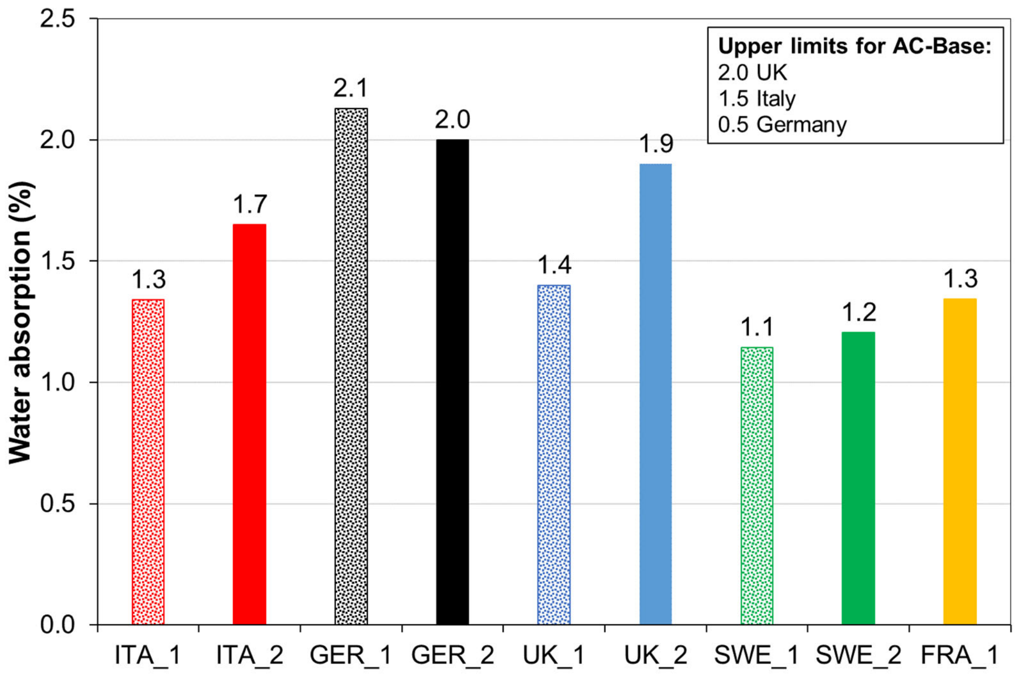


Figure 8. Physical properties of RA aggregate sources: water absorption

Table 16. - Categories for water absorption values of RA according to EN 13043

ID	EN13043
ITA_1	$WA_{24}2$
ITA_2	$WA_{24}2$
GER_1	Unclassifiable
GER_2	$WA_{24}2$
UK_1	$WA_{24}2$
UK_2	$WA_{24}2$
SWE_1	$WA_{24}2$
SWE_2	$WA_{24}2$
FRA_1	$WA_{24}2$

3.3.8. Resistance to Freezing and Thawing

Figure 9 summarises the results of the resistance to freezing and thawing in terms of Los Angeles reduction (ΔLA). The test was carried out on all the RA aggregate sources, despite according to EN 13043 it was required only for GER_1 (Section 3.3.7). Most of the RA showed ΔLA lower than zero, highlighting that the materials do not have a significant susceptibility to freezing and thawing. This may also indicate that the samples tested in terms of resistance to fragmentation and resistance to freezing and thawing were heterogenous.

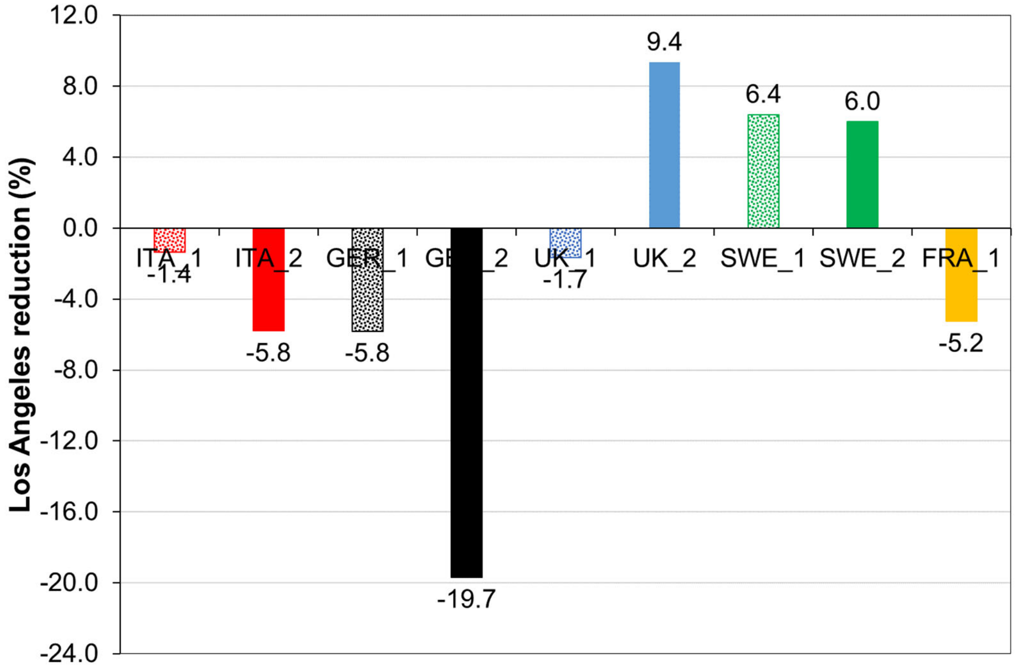


Figure 9. Thermal and weathering properties of RA aggregate sources: reduction of Los Angeles coefficient due to freezing and thawing cycles

3.3.9. Rise in pH

The reactivity of the 9 RA aggregate was studied with the same acidified aqueous phase (pH = 1.95) with a cationic emulsifier. Figure 10 shows the change in pH for a maximum time period of 1 to 2 hours. The pH of the reactive mixtures increased towards a value that stabilised more or less quickly (around the pH of 6). As shown in the figure, aggregates can be ranked into two categories: reactive (GER1, GER2, ITA1, ITA2, FR1, UK2) and non-reactive (SWE2, SWE2, UK1). The case of RA GER1 is qualified as an “intermediate reactive material” since the rise in pH is very slow but significant.

Figure 10 to Figure 13 show the reactivity of the RA extracted without binder (coded “e” for binder extracted). The results indicate that the bitumen has no effect on the kinetics of the mineral fractions rise in pH. pH rises were similar (ITA1, SWE1, FR1, UK1) as shown in Figure 11 and Figure 12. In the case of RA GER1 (Figure 11 and Figure 12) and GER2 (Figure 13), a final state is observed after 1 hour of immersion in the aqueous phase (pH equal to 3.7 and 5.2 for GER1, pH equal to 4.0 and 5.9 for GER2) but a different path. This difference may be linked to the homogeneity of the sample taken on the uncoated RA after binder extraction. The rise in pH results from the acid attack on the mineral surface and the specific surface of the samples. A RA is a mixture made of fine to coarse aggregates. After extraction process, the bitumen no longer maintains this aggregate backbone and the fine and coarse elements are dissociated. It would suffice to recover one part more than the other to modify the size composition of the mixture. This modification in size can have an impact on the composition of the mixtures and the reactivity of the finest fractions which in general are composed of calcareous elements, more friable but also more reactive.

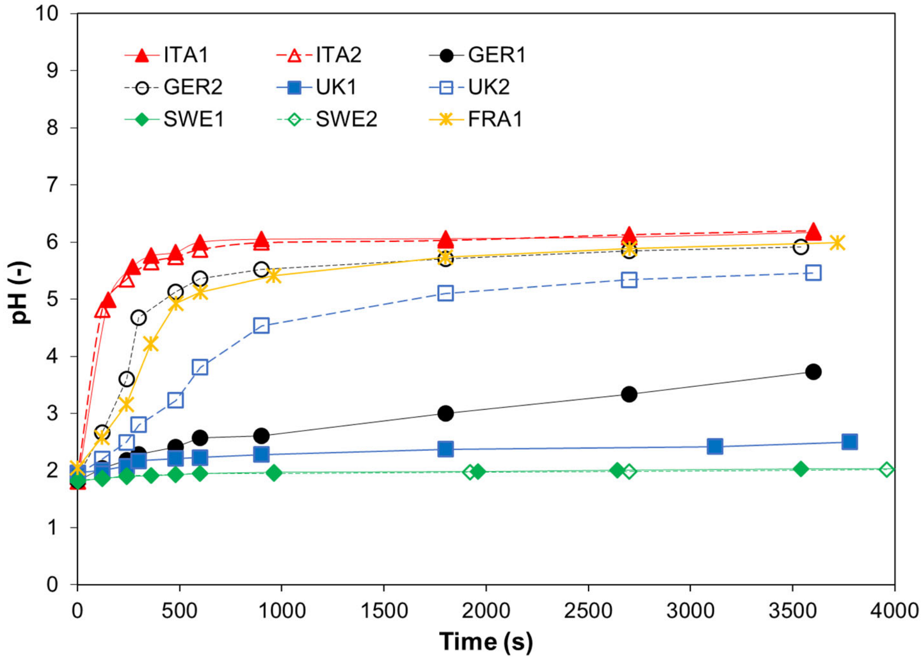


Figure 10. Rise in pH of the nine RA aggregate samples characterised

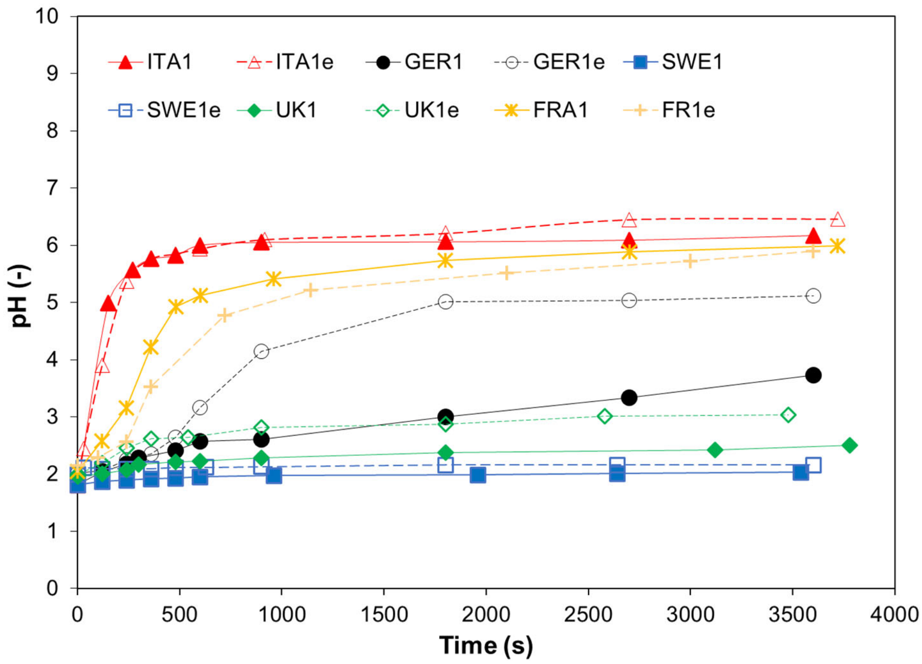


Figure 11. Rise in pH of five of the RA aggregate samples characterised and the corresponding extracted aggregate

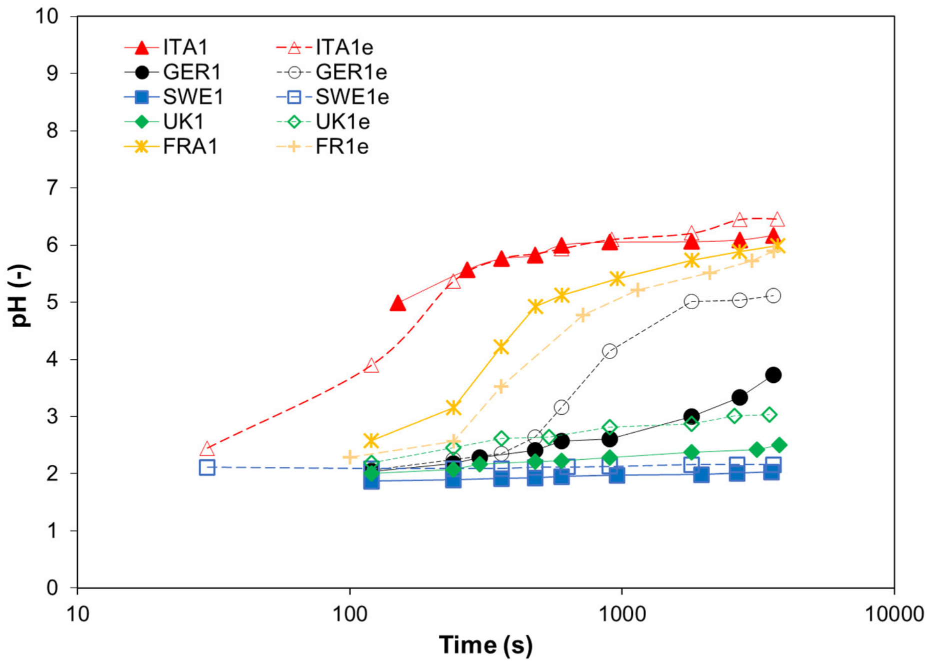


Figure 12. Rise in pH of five of the RA aggregate samples characterised and the corresponding extracted aggregate (time in log scale)

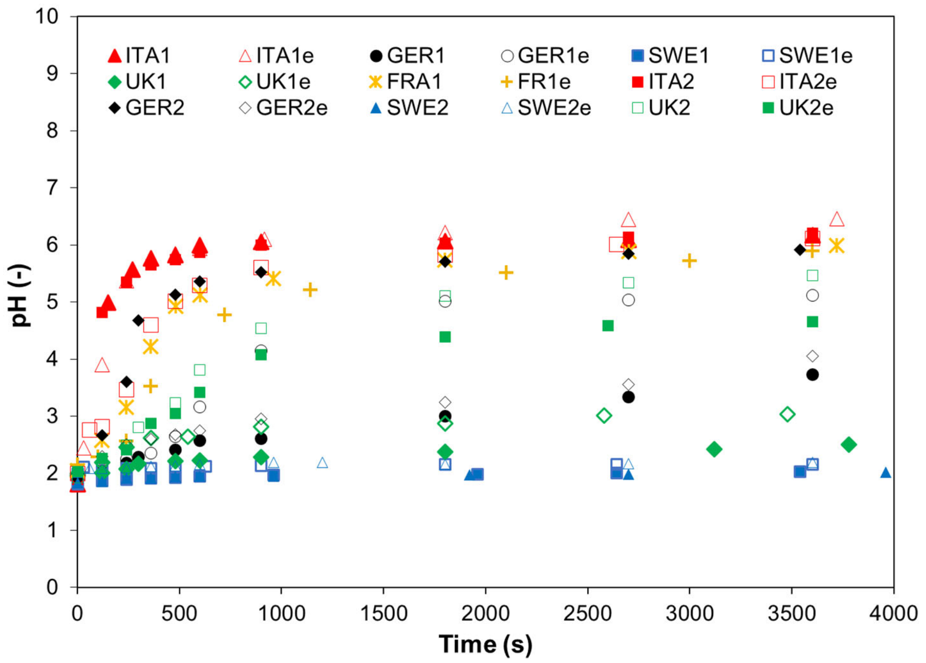


Figure 13. Rise in pH of the nine RA aggregates extracted compared to those of the coated aggregates

Figure 14 shows the reactivity of the extracted aggregate from GER1 (i.e. GER1e) when also cement is added. The behaviour is strongly influenced by the cement presence and dosage. A strong and quick increase in pH is observed when the cement was added. The dispersion of GER1e + 1% of cement showed a similar rising in pH (pH=7 after 1 hour) than those with only 1% of cement. It means that the rise of pH is ruled by the cement only. A dosage of 3% with

GER1e showed an even stronger and faster rise in pH (pH = 9 after 1 hour). Therefore, the breaking of the emulsion is expected to occur quicker when cement is added in the mixture, leading to an early decrease in its workability.

Figure 15 compares the rise in pH of ITA1, ITA1e in aqueous solution and ITA1e in cationic emulsion (with bitumen). The reactivity of the same aggregate immersed in an acid aqueous phase or in a cationic emulsion with a high content of bitumen was very close.

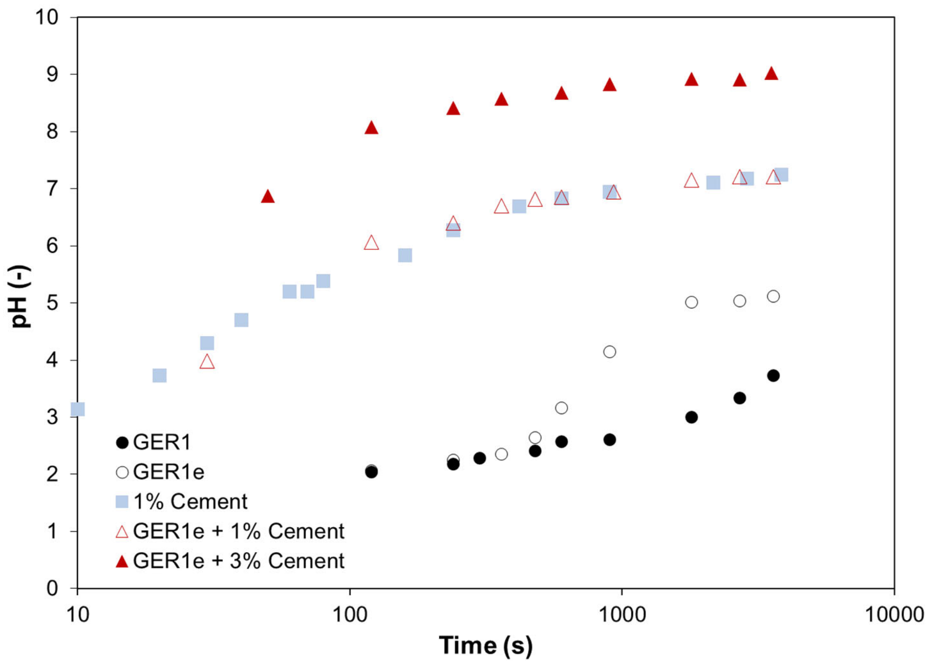


Figure 14. Rise in pH of the GER1 RA aggregate extracted in presence of cement

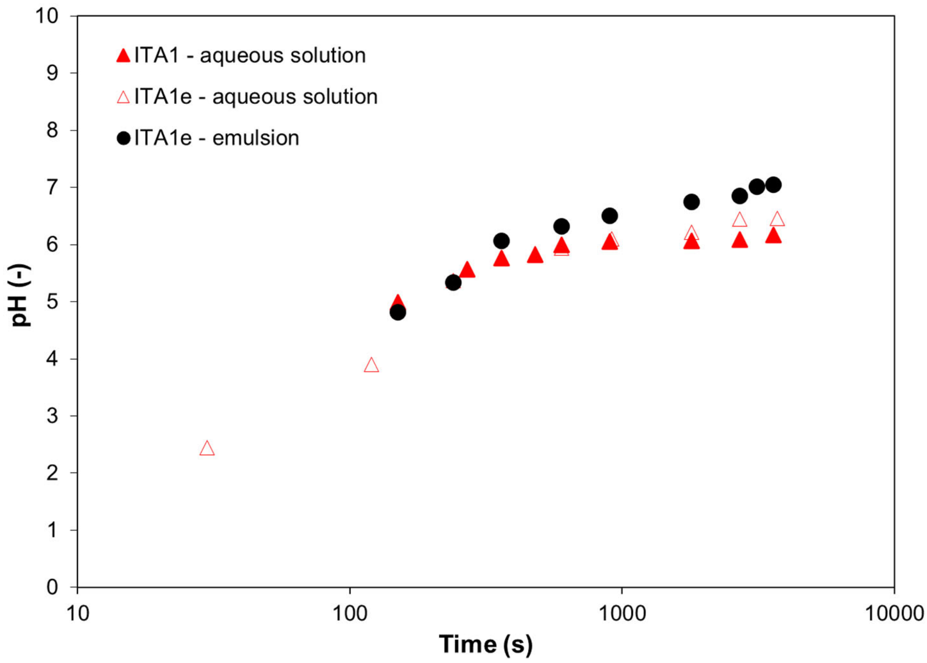


Figure 15. Rise in pH of the ITA1 RA aggregate in aqueous solution and in cationic bitumen emulsion

3.3.10. XRD test

Figure 16 shows the results obtained from XRD tests on the extracted aggregates of the fine RA particles (passing to 2 mm sieve). The aggregates show especially differences regarding the proportions of Quartzite (Qz) and Calcite (Cc). The RA samples with low reactivity according to pH-rise tests (SWE1, SWE2 and UK1) show no or only a low peak, identifying the presence of Calcite, as important mineral in limestone aggregates. High Calcite proportions (GER2, ITA1, ITA2) result in high reactivity. This shows that the reactivity of RA aggregates are controlled by the aggregate mineralogy despite the presence of (partial) bitumen coating.

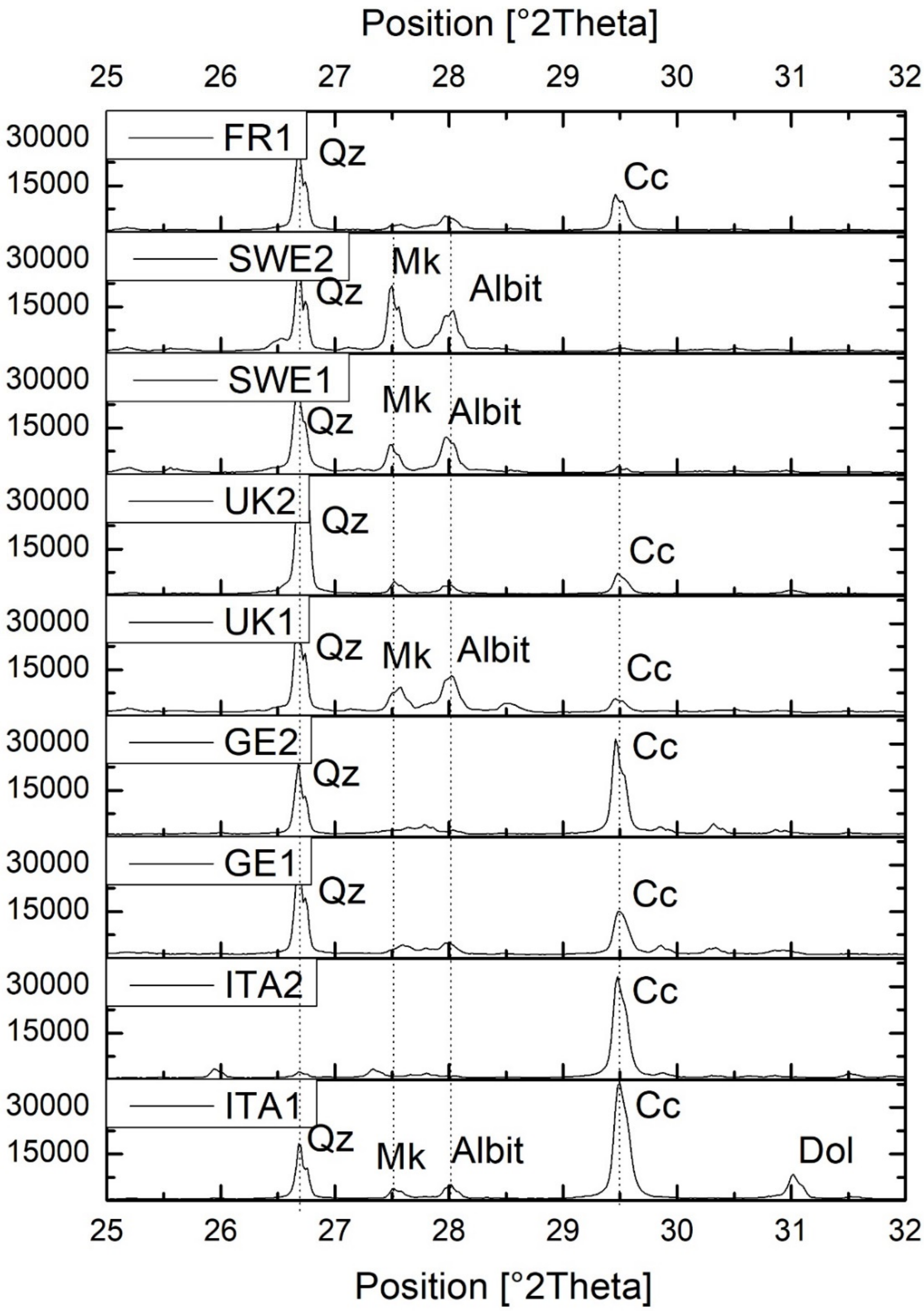


Figure 16. XRD results of aggregates extracted from fine RA fraction

3.3.11. Fragmentation test

Figure 17 reports the results of the fragmentation test obtained in terms of passing control sieve (PCS). PCS values range between 5.7% and 8.6% indicating low variability in terms of RA stability under compaction.

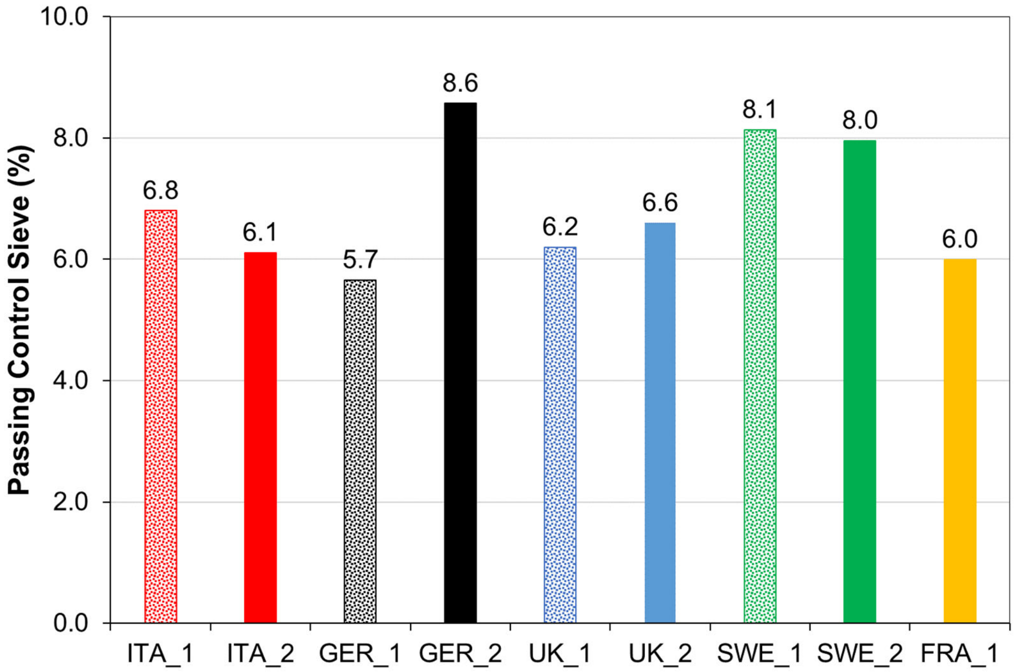


Figure 17. Fragmentation test results (PCS) of the RA aggregate samples characterised

3.3.12. Liquid Limit and Plasticity Index

All the nine RA aggregates samples gave same results in terms of Liquid limit (W_L) and plasticity index (PI). W_L was always not determinable, and PI indicated no plasticity. Thus, RA aggregates did not appear clayey.

3.4. Relationships among the measured properties

Figure 18 shows the data matrix obtained by combining the properties of the eleven RA sources. The percentage of crushed aggregate particles, liquid limit, and plasticity index were not considered since they are equal for all the RA sources. Among them, some of the properties were compared more in detail for evaluating possible correlations (highlighted in blue). Specifically, the soluble binder content and the pH value at the end of the rise in pH test have been correlated to all the remaining properties. Besides, other comparisons were evaluated, for example considering properties obtained on similar grading fractions.

The correlation was evaluated using the Spearman's rank correlation coefficient rs, reported in the following figures.

Figure 18. Data matrix of the RA properties[1]

[1] D=nominal maximum aggregate size, f=fines content, FI=flakiness index, SI=shape index, SE=sand equivalent, LA=Los Angeles, dLA=Los Angeles reduction (resistance to freezing and thawing), WA24=water absorption, B=soluble binder content, PH=rise in pH, PCS=passing control sieve (fragmentation test)

In general, the soluble binder content B appeared not related to the other properties (Figure 19, Figure 20 and Figure 21). There was no relationship between B and fines content f. Assuming that the contribution of the coarser particles is reduced, the result may indicate that the binder content does not depend only on the quantity of fines, but also on the percentage of sand size particles (Figure 19b). A slight correlation exists between B and PCS from fragmentation test (Figure 21b).

No relation was found between B and the pH at the end of the rise in pH test on RA aggregate (coated with bitumen) (Figure 21a). This confirms that the reactivity of the RA aggregates is not connected with the amount of binder coating its particles, but rather could be related with the binder properties, the mineralogy of the aggregate, the shape of the particles, the amount of fines etc..

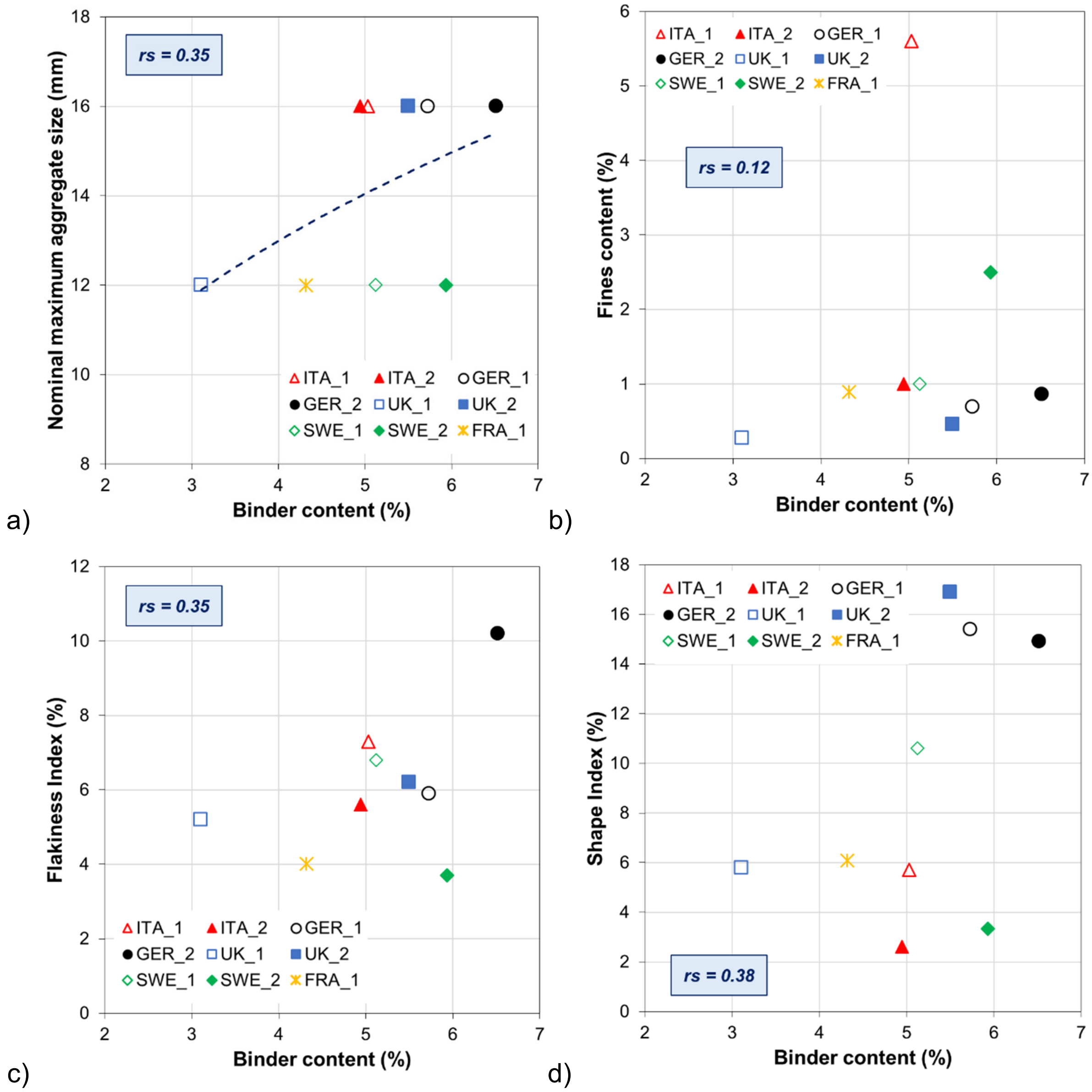


Figure 19. Soluble binder content vs a) nominal maximum aggregate size, b) fines content, c) flakiness index, d) shape index

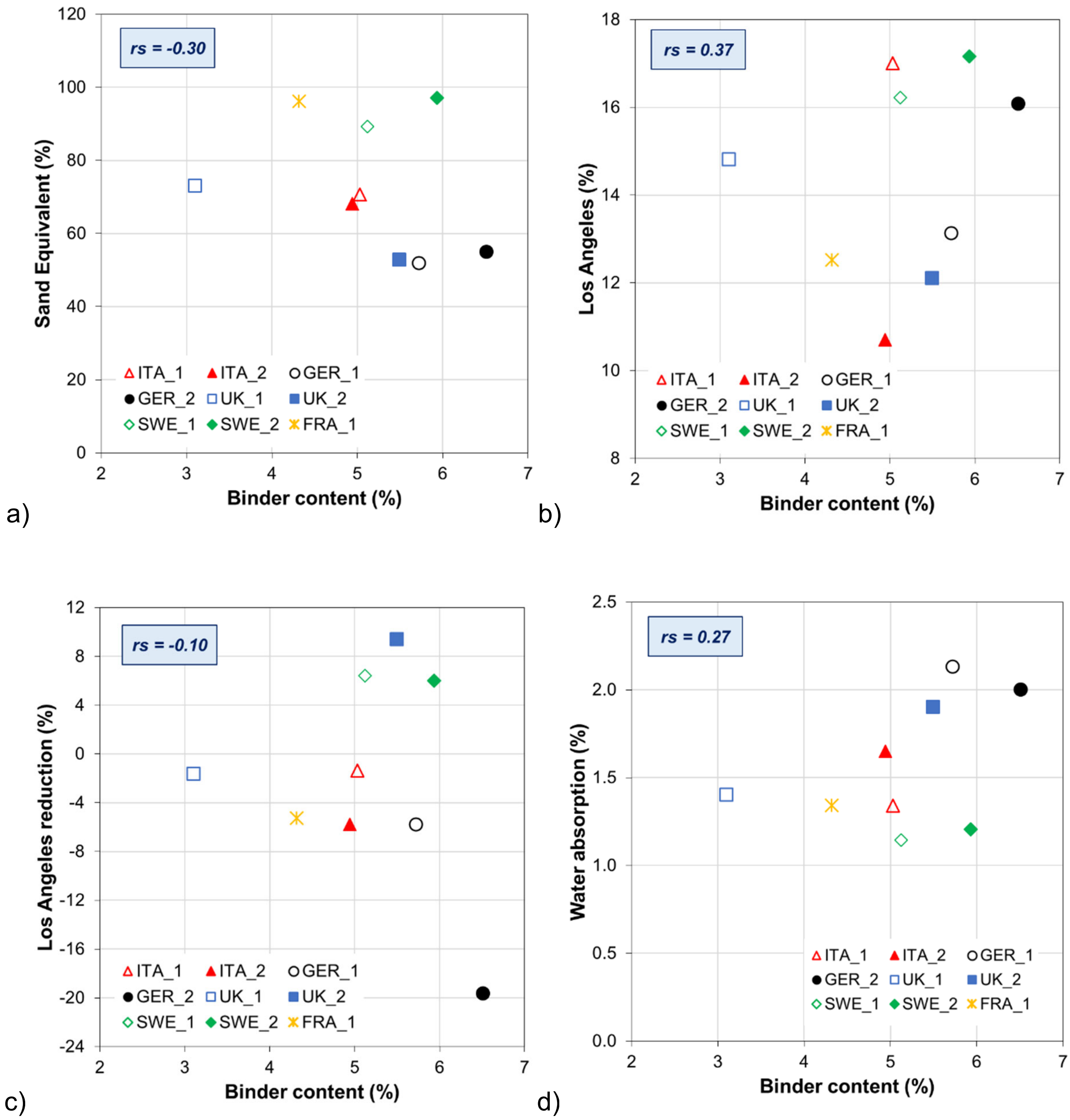
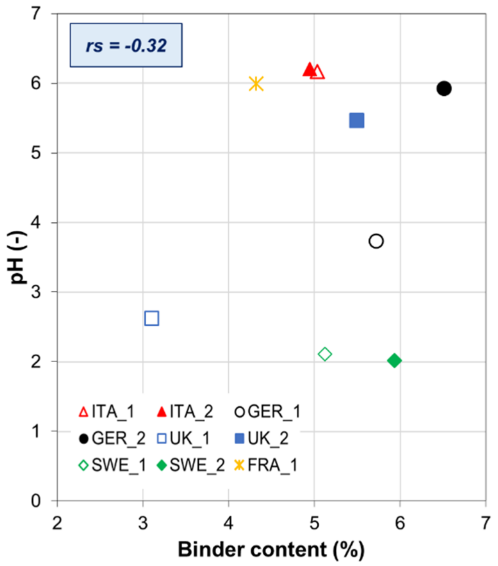
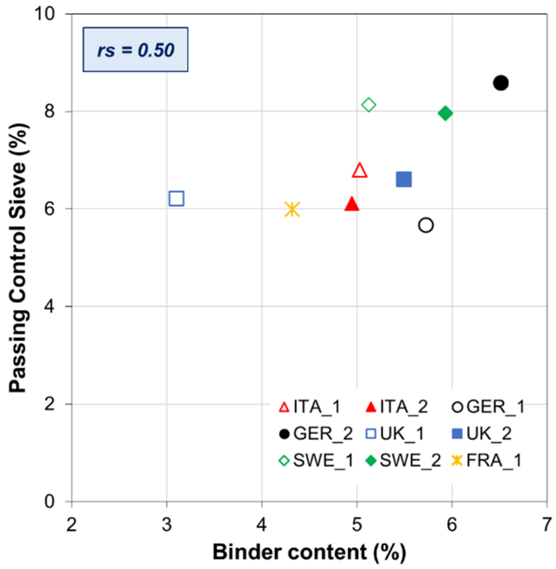


Figure 20. Soluble binder content vs a) sand equivalent, b)Los Angeles coefficient, c) Los Angeles reduction, b) water absorption



a)



b)

Figure 21. Soluble binder content vs a) pH (end of rise in pH test), b) passing control sieve (fragmentation test)

Figure 22 and Figure 23 show the comparison between the pH values obtained at the end of the rise in pH test and the other properties of the RA aggregates. The values of pH show some correlation with LA (Figure 23a) and ΔLA (Figure 23b). In particular, decreasing LA and ΔLA entailed an increased pH value. Such relationships are worth being further investigated and confirmed, as the reactivity of the RA could be an important parameter in the design of CRAB mixtures composition.

Figure 24 compares the f values with SE (obtained on the 0/2 fraction) and WA_{24}. The latter and the quantity of fines appears slightly related.

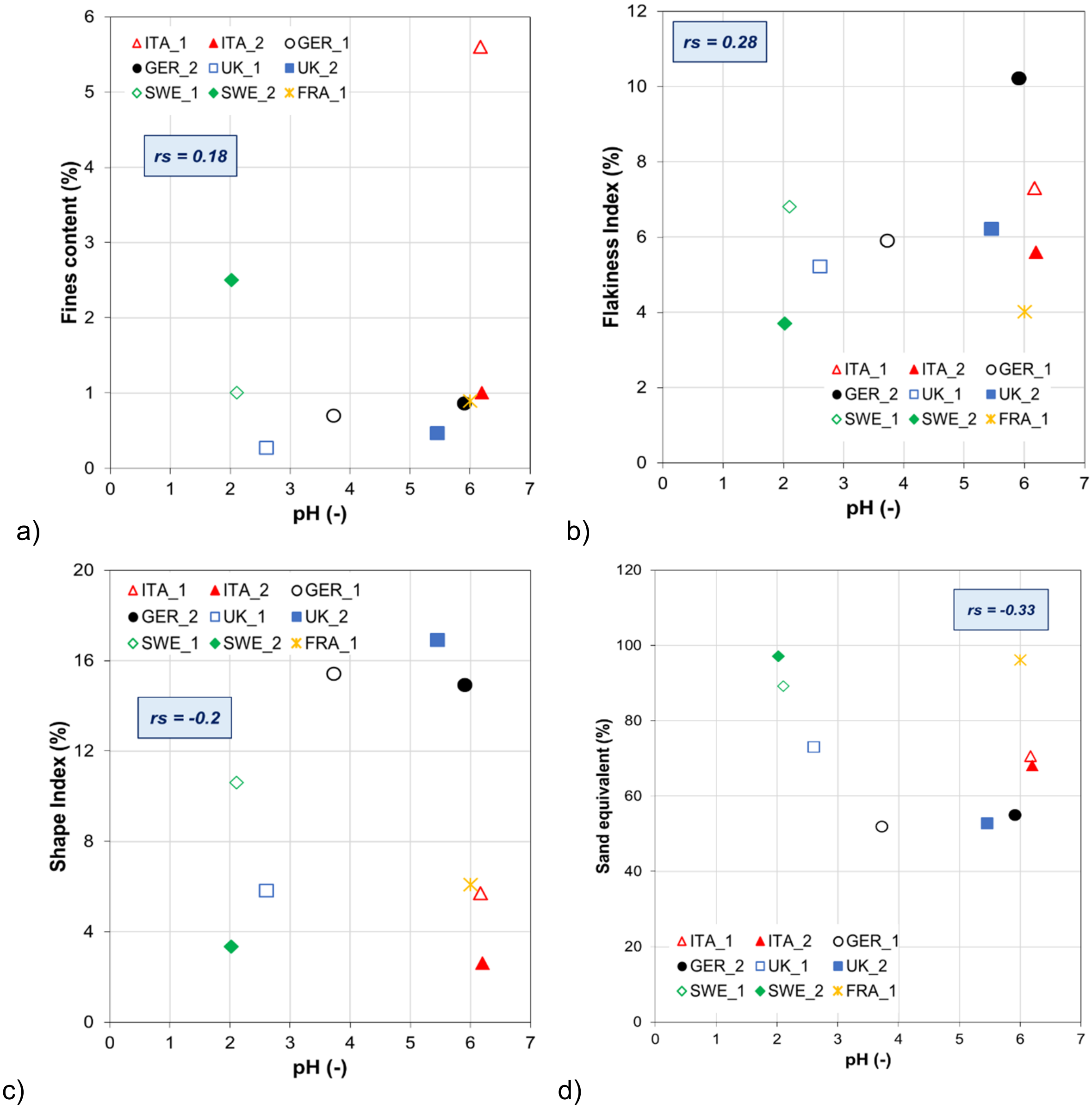


Figure 22. pH (end of rise in PH test) vs. a) fines content, b) flakiness index, c) shape index, d) sand equivalent

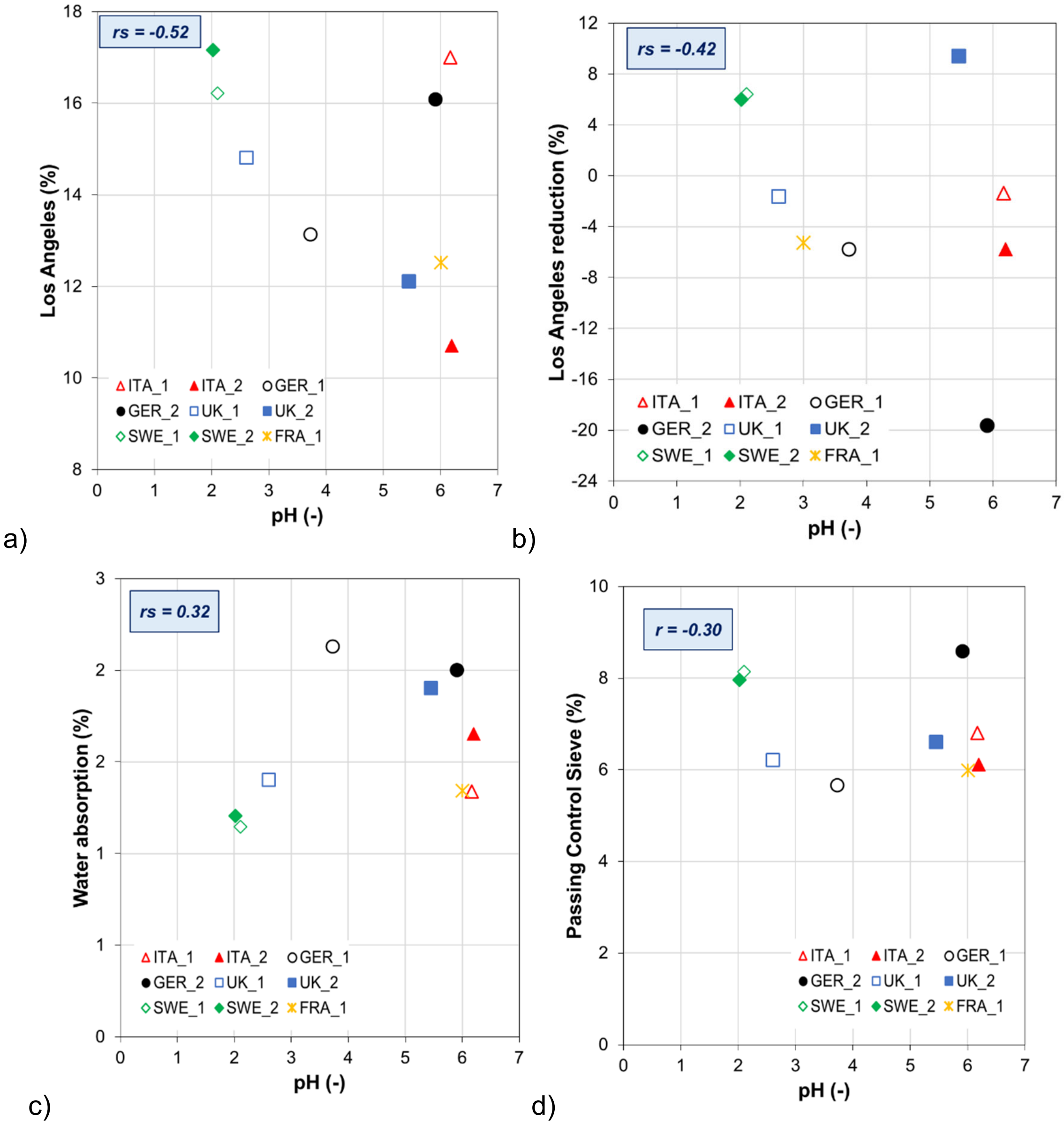


Figure 23. pH (end of rise in PH test) vs. a) Los Angeles coefficient, b) Los Angeles reduction, c) water absorption, d) passing control sieve (fragmentation test)

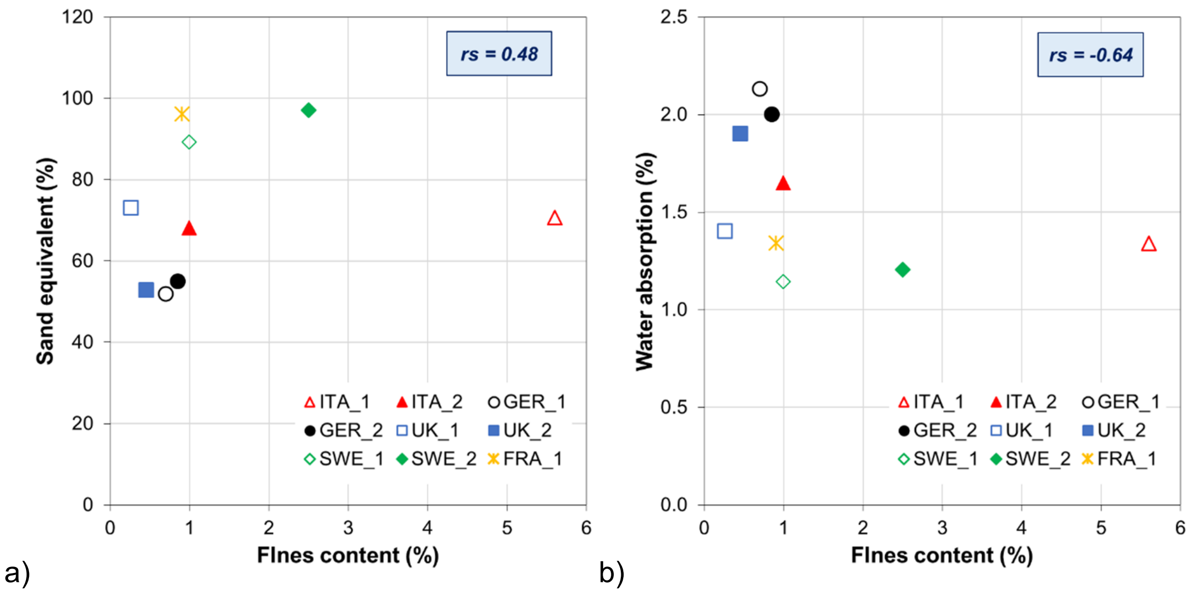


Figure 24. Fines content vs a) sand equivalent, b) water absorption

Figure 25 compares the properties of aggregates obtained on the coarse fractions (> 4 mm): LA, FI and SI. No relationships were found between LA and the two geometrical properties. On the contrary, a quite slight relation between FI and SI existed (Figure 25c).

Figure 26 expresses WA_{24} as a function of SE, ΔLA and PCS. A strong relationship was found between WA_{24} and SE. The increase in SE resulted in a decrease of WA_{24}. Also, some correlation was found between WA_{24} and ΔLA confirming the relationship suggested in the Standard EN 13043, which directly relates the value of WA_{24} to the recommendation of determining the freezing and thawing resistance of the material. This may be due to the low values of WA_{24} which generally indicates low thermal sensibility. No relations between WA_{24} and PCS was observed.

Figure 27 compares the values of PCS with those of LA and ΔLA. The relations among these parameters are fairly good, indicating that the fragmentation test has a good potential in providing a quick characterization of the RA aggregate in the field.

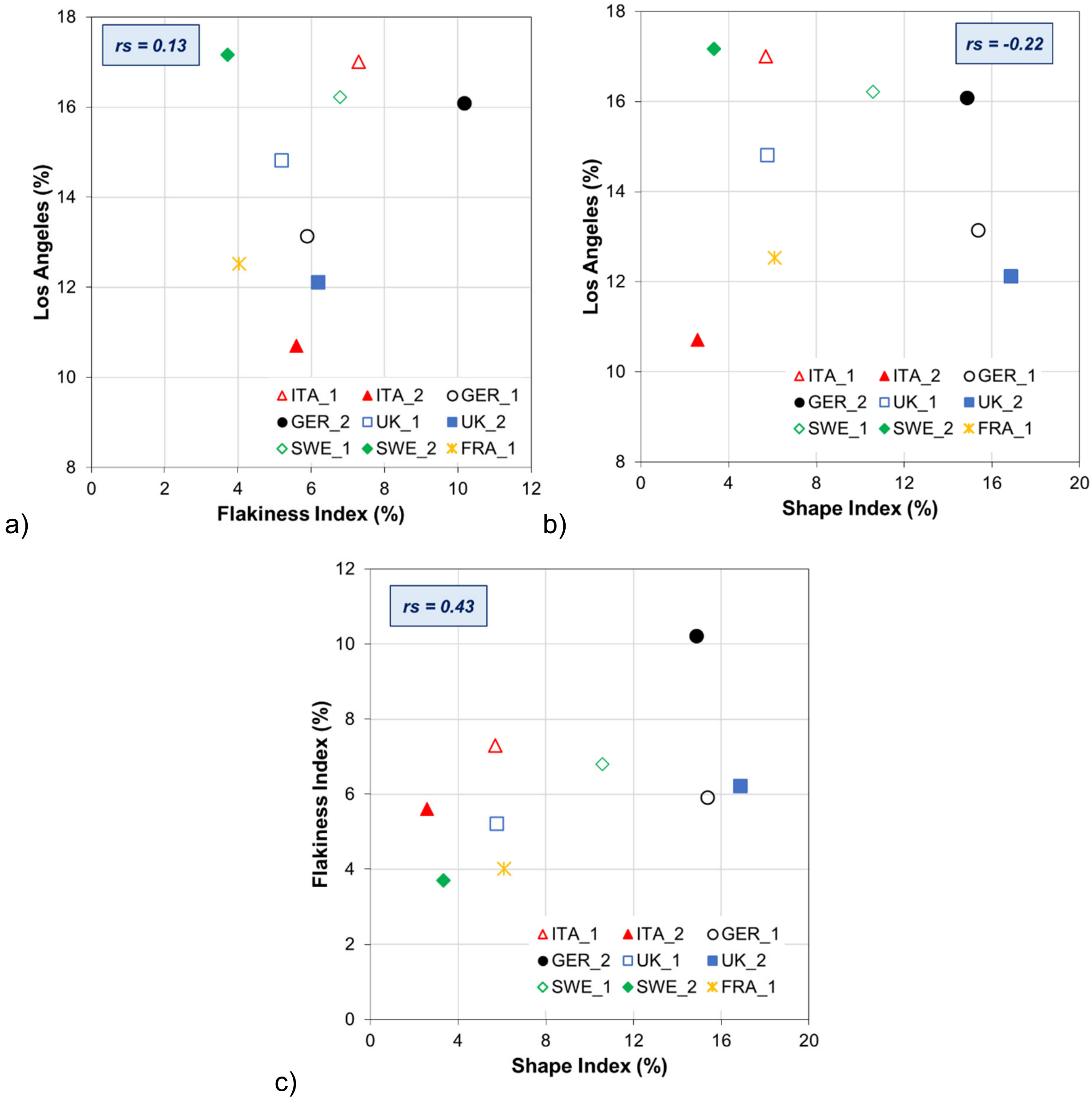


Figure 25. Geometrical properties comparison: a) flakiness index vs Los Angeles coefficient, b) shape index vs Los Angeles coefficient, c) shape index vs flakiness index

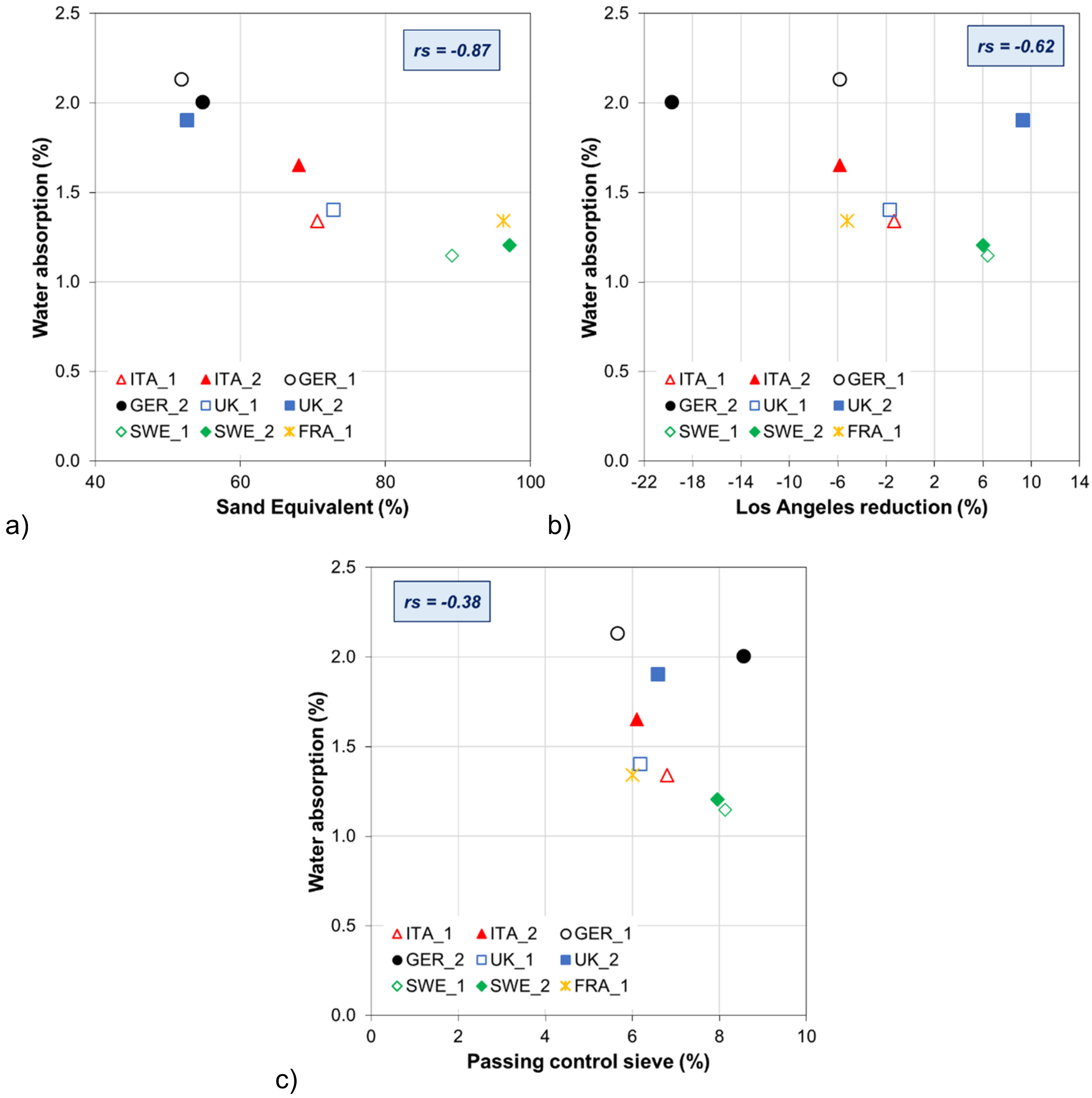


Figure 26. Water absorption expressed as a function of a) sand equivalent, b) Los Angeles reduction, c) passing control sieve (fragmentation test)

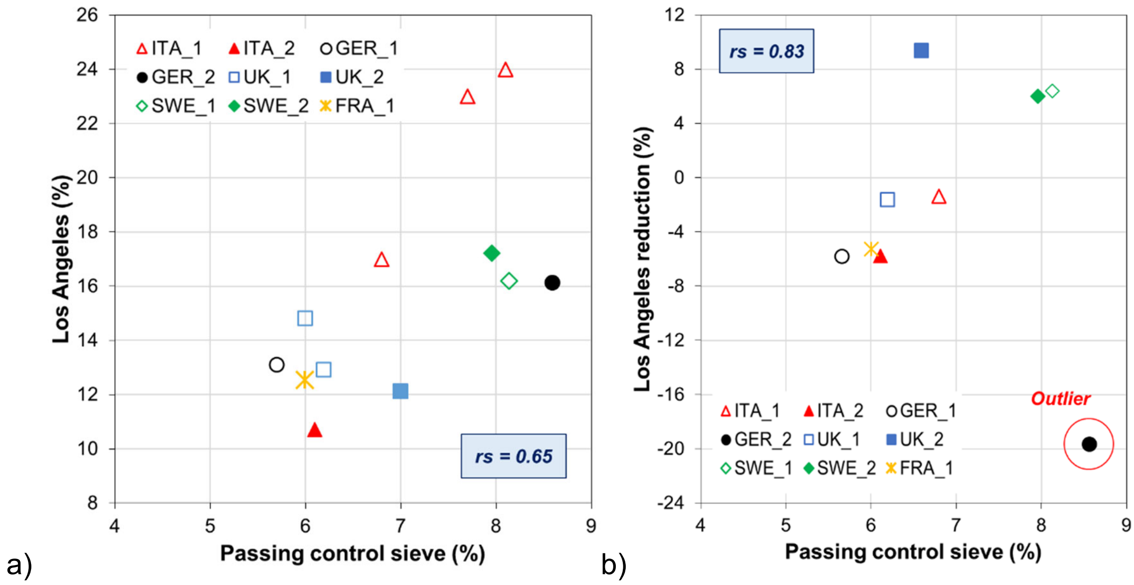


Figure 27. Passing control sieve vs a) Los Angeles coefficient, b) Los Angeles reduction

4. Recommendations for characterising RA

Table 17 reports recommendations for the characterisation of RA aggregate to be used in CRAB mixtures. The recommendations were defined based on the National Specifications review and the characterisation of several RA sources.

Table 17. List of recommendations

Requirement	Recommendations
Upper aggregate size (mm)	Should be determined
Maximum value of fines content	Should be determined Crushing process at the plant recommended to increase the amount of fines and reducing the natural aggregate required for adjustment of the mix granulate grading
Flakiness index	Should be determined
Shape Index	Should be determined
Crushed aggregate particles	Not recommended
Sand Equivalent	Should be determined Pay attention in the storage and collection of the RA
Resistance to fragmentation (Los Angeles)	Should be determined
Resistance to freezing and thawing	Should be determined only for high values of WA_{24}
Water Absorption	Should be determined More categories should be introduced for RA classification
Limit Liquid	Not recommended
Plasticity index	Not recommended
Fragmentation test	Not recommended
Rise in pH	Should be determined
Soluble binder content	Should be determined

5. Conclusions

The following conclusions can be drawn from the assessment discussed within this report:

1. The National specifications seldom explicitly consider RA aggregate or give indications on its use in CRAB mixtures. Besides, the set of required properties and their limits is quite heterogeneous and should be harmonised.
2. A set of consensus RA aggregate properties that should be determined has been proposed.
3. RA aggregate can be characterised using the same procedures introduced in the European Standards for natural aggregate. Caution should be paid in using lower temperatures for oven-drying.
4. RA aggregate properties generally fall within the limits required for the properties of natural aggregates.
5. New tests should be introduced for characterising RA aggregate for CRAB mixtures and specific requirements should be introduced. In particular, the rise in pH test is important to assess the reactivity of the aggregate when in contact with cationic emulsion, especially if cement is not used. Moreover, despite the presence of (partial) bitumen coating, the results showed that the rise in pH is well correlated to the mineralogy of the aggregate extracted from the RA.
6. The fragmentation test can be used to provide quick indication about the stability of the aggregate during compaction operations. Its standardization should be considered.
7. In general, the consensus properties do not relate to each other, which confirms that their measurement is needed. In some cases, some correlation was observed that deserves being explored to eventually reduce the number of tests needed to fully characterise the RA aggregate.

RA aggregate demonstrated being a high-quality material for producing CRAB mixtures, showing properties which can be compared to those of good quality natural aggregates. However, it must be treated as such since its collection. Attention should be paid in the plant, introducing crushing and screening before stockpiling, keeping track of the origin of the RA sources, and paying proper attention on the storage. Besides, RA aggregate should be adequately characterised for making choices on the CRAB mixtures materials and composition. This could help in obtaining CRAB mixtures with enhanced performance.

References

Graziani, A., Raschia, S., Mignini, C., & Carter, A. (2020). Use of fine aggregate matrix to analyze the rheological behavior of cold recycled materials. *Materials and Structures*, *7*. https://doi.org/10.1617/s11527-020-01515-7

LoPresti, D., Vasconcelos, K., Orešković, M., Pires, G. M., & Bressi, S. (2020). On the degree of binder activity of reclaimed asphalt and degree of blending with recycling agents. *Road Materials and Pavement Design*. https://doi.org/10.1080/14680629.2019.1607537

Mollenhauer, K., & Simnofske, D. (2015). Tolerances for inhomogeneity of pavement structure for in-situ cold recycling. *Proceedings 3rd ISAP TC APE Asphalt Pavements and Environment Symposium, Sun City*. https://doi.org/10.14311/ee.2016.151

Odie, L., Le Cunff, F., & Naudat, C. (2011). *Réactivité physico-chimique d'un couple émulsion de bitume/granulats Suivi du pH et dosage des éléments alcalins (Na, Ca, K et Mg) par spectrophotométrie d'absorption atomique VIAF (in French)*.

Perraton, D., Tebaldi, G., Dave, E., Bilodeau, F., Giacomello, G., Grilli, A., Graziani, A., Bocci, M., Grenfell, J., Muraya, P., Pasetto, M., Kuna, K., Apeagyei, A., Lo Presti, D., Airey, G., Jenkins, K., Hajj, E., Hugener, M., & Marsac, P. (2016). Tests campaign analysis to evaluate the capability of fragmentation test to characterize recycled asphalt pavement (RAP) material. *RILEM Bookseries*. https://doi.org/10.1007/978-94-017-7342-3_77

Stimilli, A., Virgili, A., & Canestrari, F. (2015). New method to estimate the "re-activated" binder amount in recycled hot-mix asphalt. *Road Materials and Pavement Design*. https://doi.org/10.1080/14680629.2015.1029678

Ziyani, L., Gaudefroy, V., Ferber, V., Deneele, D., & Hammoum, F. (2014). Chemical reactivity of mineral aggregates in aqueous solution: Relationship with bitumen emulsion breaking. *Journal of Materials Science*, *49*(6), 2465–2476. https://doi.org/10.1007/s10853-013-7938-9

List of Annexes

A. List of requirements

a. Italy

Table 18: List of the aggregate requirements for UM in CSA1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13242)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f			
Flakiness index (%)	EN 933-3	FI		35	FI35
Shape Index (%)	EN 933-4	SI		40	SI40
Crushed aggregate particle (%)	EN 933-5	C	70	150	C70/NR
Totally rounded particle (%)	EN 933-5	C	NR	NR	C70/NR
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	50		SE50
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ		32	SZ32
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		1	F1
Limit Liquid (%)	CEN ISO/TS 17892-12	WL		15	
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1		0	0	
Water soluble components (%)	EN 1744-3		0	0	
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

Table 19: List of the aggregate requirements for UM in CSA2

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13242)
Upper aggregate size (mm)	EN 933-1	D		71	
Maximum value of fines content (%)	EN 933-1	f			
Flakiness index (%)	EN 933-3	FI			
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	30	60	
Totally rounded particle (%)	EN 933-5	C			
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	25	65	
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47		50		
Soundness (%)	BS 812-121				

Table 20: List of the aggregate requirements for HBM in CSA1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13242)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f		1	f1
Flakiness index (%)	EN 933-3	FI		35	FI35
Shape Index (%)	EN 933-4	SI		40	SI40
Crushed aggregate particle (%)	EN 933-5	C	70	150	C70/NR
Totally rounded particle (%)	EN 933-5	C	NR	NR	C70/NR
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	50		SE50
Methylene blue	EN 933-9	MB		15	MB15
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ		32	SZ32
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS		25	MS25
Resistance to freezing and thawing (%)	EN 1367-1	F		1	F1
Limit Liquid (%)	CEN ISO/TS 17892-12	WL		15	
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24		1.5	WA252
Organic substance (%)	EN 1744-1		0	0	
Water soluble components (%)	EN 1744-3		0	0	
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

Table 21: List of the aggregate requirements for HBM in CSA2

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		40	
Maximum value of fines content (%)	EN 933-1	f			
Flakiness index (%)	EN 933-3	FI			
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	30	60	
Totally rounded particle (%)	EN 933-5	C			
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	30	60	
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

Table 22: List of the aggregate requirements for CBSM in CSA1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		40	
Maximum value of fines content (%)	EN 933-1	f		1	f1
Flakiness index (%)	EN 933-3	FI		30	FI30
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	70	150	C70/0[(1)]
Totally rounded particle (%)	EN 933-5	C		0	C70/0[(1)]
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	60		
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		25	LA25
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		1	F1
Limit Liquid (%)	CEN ISO/TS 17892-12	WL		25	
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24		1.5	WA242
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

[(1)] Category not defined in EN 13043

Table 23: List of the aggregate requirements for CBSM in CSA2

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		40	
Maximum value of fines content (%)	EN 933-1	f			
Flakiness index (%)	EN 933-3	FI			
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	30	60	
Totally rounded particle (%)	EN 933-5	C			
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	30	60	
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

Table 24: List of the aggregate requirements for ACBM in CSA1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f		1 / 2 (1)	f1 / f2 (1)
Flakiness index (%)	EN 933-3	FI		30	FI30
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	150		C150/0
Totally rounded particle (%)	EN 933-5	C		0	C150/0
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	60		
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		1	F1
Limit Liquid (%)	CEN ISO/TS 17892-12	WL		25	
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24		1.5	WA242
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(1) For coarse / fine aggregate

Table 25: List of the aggregate requirements for BM in CSA1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		40	
Maximum value of fines content (%)	EN 933-1	f		1 / 2 [(2)]	f1 / f2 [(2)]
Flakiness index (%)	EN 933-3	FI		30	FI30
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	70	150	C70/0[(1)]
Totally rounded particle (%)	EN 933-5	C		0	C70/0
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	70		
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		1	F1
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24		1.5	WA242
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(1) Category not defined in EN 13043

(2) For coarse / fine aggregate

Table 26: List of the aggregate requirements for BM in CSA2

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f			
Flakiness index (%)	EN 933-3	FI		15	FI15
Shape Index (%)	EN 933-4	SI		15	SI15
Crushed aggregate particle (%)	EN 933-5	C	60		C50/15 or C50/30
Totally rounded particle (%)	EN 933-5	C		0	
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE	70		
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		25	LA25
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		2	F2
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI	0	0	NP
Water Absorption (%)	EN 1597-6	WA24			TBD
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

b. Germany

Table 27: List of the aggregate requirements for BM in TLA

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		32	
Maximum value of fines content (%)	EN 933-1	f		1 / 2 (2)	f1 / f2 (2)
Flakiness index (%)	EN 933-3	FI		50	FI50
Shape Index (%)	EN 933-4	SI		50	SI50
Crushed aggregate particle (%)	EN 933-5	C	50 (3)	150 (3)	C50/30 (3)
Totally rounded particle (%)	EN 933-5	C	0 (3)	30 (3)	C50/30 (3)
Angularity of fine aggregates	EN 933-6	Ecs			TBD
Sand Equivalent (%)	EN 933-8	SE			
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		25/50 (4)	LA25/LA50 (4)
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F		4	F4
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24		0.5	WA240.5
Organic substance (%)	EN 1744-1			0.1	mLPC0.1
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(2) For coarse / fine aggregate
(3) Requested only for special level of traffic, not required in the other cases
(4) As a function of aggregate type

c. United Kingdom

Table 28: List of the aggregate requirements for CRBM in MCHW1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f	5	20	
Flakiness index (%)	EN 933-3	FI			
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C			
Totally rounded particle (%)	EN 933-5	C			
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE			
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS		25	MS25
Resistance to freezing and thawing (%)	EN 1367-1	F		4	F4
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			TBD (5)
Organic substance (%)	EN 1744-1			0.1	mLPC0.1
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				TBD (5)

(5) if WA242 the soundness test shall be carried out

Table 29: List of the aggregate requirements for BM in MCHW1

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		40	
Maximum value of fines content (%)	EN 933-1	f		NR/1/15 [(6)]	fnr/f1/f15 [(6)]
Flakiness index (%)	EN 933-3	FI		35	FI35
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C			
Totally rounded particle (%)	EN 933-5	C			
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE			
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS		25	MS25
Resistance to freezing and thawing (%)	EN 1367-1	F		4	F4
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			TBD [(5)]
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				TBD [(5)]

[(4)] if WA24 > 2 the soundness test shall be carried out
[(6)] crushed rock, slag / gravel / sand

d. Sweden

Table 30: List of the aggregate requirements for UM in TDOK 2013:0530

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D			
Maximum value of fines content (%)	EN 933-1	f		7	
Flakiness index (%)	EN 933-3	FI			
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	50		C50/30
Totally rounded particle (%)	EN 933-5	C		30	C50/30
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)(11)	EN 933-8 (1999)/ EN 933-8:2012	SE	30		
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA			
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1097-1	MDE		25(12)	MDE25
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1			2	
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(11) If the fines content ≥ 5 %, a requirement on SE value is set to minimum 30 according to EN 933-8 (1999); alternatively, according to EN 933-8:2012 and the minimum requirements then are those for the category $SE10_{40}$.
(12) If the subbase layer is not exposed to traffic, MDE up to 30 is allowed.

Table 31: List of the aggregate requirements for BM in TDOK 2013:0529

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D	16	45	
Maximum value of fines content (%)	EN 933-1	f	2	7	
Flakiness index (%)	EN 933-3	FI		20/25(13)	FI20/FI25
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	90/100(14)		C90/1 / C100/0
Totally rounded particle (%)	EN 933-5	C		1/0(14)	C90/1 / C100/0
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)(12)	EN 933-8	SE			
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30/25(15)	LA30/LA25
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval) (12)	EN 1597-1	MDE		15	MDE15
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(13) For aggregates >8 mm and ≤8 mm, respectively.
(14) For ADT≤2000 and ADT>2000, respectively.
(15) For ADT≤500 and ADT>500 respectively.

Table 32: List of the aggregate requirements for CRBM in TDOK 2013:0529

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D		31.5	
Maximum value of fines content (%)	EN 933-1	f		2	f2
Flakiness index (%)	EN 933-3	FI		20	FI20
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	50		C50/30
Totally rounded particle (%)	EN 933-5	C		30	C50/30
Angularity of fine aggregates	EN 933-6	Ecs			
Sand Equivalent (%)	EN 933-8	SE			
Methylene blue	EN 933-9	MB			
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30	LA30
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE			
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

e. France

Table 33: List of the aggregate requirements for GE in NFGE

Requirement	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D			
Maximum value of fines content (%)	EN 933-1	f		1/2(7)	f1/f2 (7)
Flakiness index (%)	EN 933-3	FI		25/30(8)	FI25/FI30(8)
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	50	150	C50/15
Totally rounded particle (%)	EN 933-5	C	0	15	C50/11
Angularity of fine aggregates	EN 933-6	Ecs	30		Ecs30
Sand Equivalent (%)	EN 933-8	SE	55		SE(15)55
Methylene blue	EN 933-9	MB		2	MB2
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30(9)	LA30(9)
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE		25(9)	MDE25(9)
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(7) f2 se MBF≤15
(8) FI30 if D≤6.3
(9) LA+MDE≤45

Table 34: List of the aggregate requirements for UM in IDRRIM

Requirement[(a)]	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D			
Maximum value of fines content (%)	EN 933-1	f		2	f2
Flakiness index (%)	EN 933-3	FI		35	FI35
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	90/ 50[(15)]	150[(15)]	C90/1 / C50/15[(15)]
Totally rounded particle (%)	EN 933-5	C	0[(15)]	1/ 15[(15)]	C90/1 / C50/15[(15)]
Angularity of fine aggregates	EN 933-6	Ecs	35 / 30[(15)]		Ecs35 / Ecs30[(15)]
Sand Equivalent (%)	EN 933-8	SE	45		SE(15)45
Methylene blue	EN 933-9	MB		2.5	MB2.5
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30[(9)]	LA30[(9)]
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE		25[(9)]	MDE25[(9)]
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(9) LA+MDE≤45
(15) for subbase / base courses

(a)The listed requirements refer to mixtures for subbase courses - traffic category T1 (300≤ADT≤750) and base courses - traffic category T3 (50≤ADT≤150).

Table 35: List of the aggregate requirements for HBM in IDRRIM

Requirement[a]	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D			
Maximum value of fines content (%)	EN 933-1	f		2	f2
Flakiness index (%)	EN 933-3	FI		35	FI35
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	NR(15) (11) 90(15)	NR(15) (11) 150(15)	CNR/50(15)/ C90/1(15)
Totally rounded particle (%)	EN 933-5	C	0(15) (11 0(15)	50(15) (11 1(15)	CNR/50(15)(11) / C90/1(15)
Angularity of fine aggregates	EN 933-6	Ecs	35(13)	30(12)	Ecsdeclared(12) Ecs35(13)
Sand Equivalent (%)	EN 933-8	SE	45		SE(15)45
Methylene blue	EN 933-9	MB		2.5	MB2.5
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		35(9)	LA35(9)
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE		30(9)	MDE30(9)
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	PI WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

(9) LA+MDE≤55
(15) for subbase / base courses
(11) according to EN 13242
(12) for subbase courses
(13) for base courses

(a)The requirements listed are referred to mixtures for subbase courses - traffic category ≥T0 (ADT≥2000) and base courses - traffic category ≥T0 (ADT≥2000).

Table 36: List of the aggregate requirements for BM in IDRRIM

Requirement[(a)]	Testing standard	Symbol	Lower limit	Upper limit	Category (EN 13043)
Upper aggregate size (mm)	EN 933-1	D			
Maximum value of fines content (%)	EN 933-1	f		1	F1
Flakiness index (%)	EN 933-3	FI		25	FI25
Shape Index (%)	EN 933-4	SI			
Crushed aggregate particle (%)	EN 933-5	C	50 / 90[(15)]	150[(15)]	C50/15 / C90/1[(15)]
Totally rounded particle (%)	EN 933-5	C	0[(15)]	15 / 1[(15)]	C50/15 / C90/1[(15)]
Angularity of fine aggregates	EN 933-6	Ecs	30 / 35[(15)]		Ecs30/ Ecs35[(15)]
Sand Equivalent (%)	EN 933-8	SE	55		SE(15)55
Methylene blue	EN 933-9	MB		2	MB2
Resistance to fragmentation (Los Angeles) (%)	EN 1597-2	LA		30[(9)]	LA30[(9)]
Resistance to fragmentation (Impact test) (%)	EN 1597-2	SZ			
Resistance to wear (micro-Deval)	EN 1597-1	MDE		25[(9)]	MDE25[(9)]
Magnesium sulphate test (%)	EN 1367-2	MS			
Resistance to freezing and thawing (%)	EN 1367-1	F			
Limit Liquid (%)	CEN ISO/TS 17892-12	WL			
Plasticity index	CEN ISO/TS 17892-12	PI			
Water Absorption (%)	EN 1597-6	WA24			
Organic substance (%)	EN 1744-1				
Water soluble components (%)	EN 1744-3				
California Bearing Ratio (%)	EN 13286-47				
Soundness (%)	BS 812-121				

[(9)] LA+MDE≤45
[(15)] for subbase / base courses

[(a)]The requirements listed are referred to mixtures for subbase courses - traffic category ≥T0 (ADT≥2000) and base courses - traffic category ≥T0 (ADT≥2000).