# Action 2.4

# Evaluation of the current status of aggregates available for bituminous mixtures containing crumb rubber

## POLITECNICO DI TORINO

Project partners

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With the contribution of

## Contents

## PART 1 – LOCALLY AVAILABLE STANDARD AGGREGATES

The availability of aggregates for bituminous mixtures containing scrap tyre rubber was preliminarily assessed by examining the data provided by quarries distributed in northern Italy, with an emphasis placed upon those located in the Piemonte region. Based on the gathered data, useful aggregates for mixtures considered in the study were identified. They were subjected to characterization tests according to EN standards in the laboratories of "Innovative Road Materials" and of "Environmental Chemistry" of the Politecnico di Torino.

### ANALYSIS OF AVAILABLE DATA
### Aggregates of the Piedmont Region

Available information of aggregates coming from quarries located in Piedmont was extracted from the Regional Quarry Plan, which contains data expressed in terms of:
- lithological composition;
- mineralogical composition;
- resistance to fragmentation (Los Angeles test).

Data were available on coarse (15/30 mm), intermediate (8/15 mm) and fine (0.2-0.3 mm) fractions and are synthesized in the following Tables 1-5.

Table 1. Available sites and tests

| N. | Location | Formation | Basin/Area | L.A. | Min. | Petr. |
|---|---|---|---|---|---|---|
| 1 | Trecate (NO) | Fluvio-glacial | Sesia-Ticino | sì | sì | sì |
| 2 | Turbigo (NO) | Recent alluvional | Ticino | sì | sì | sì |
| 3 | Bellinzago (NO) | Fluvio-glacial | Sesia-Ticino | sì | sì | sì |
| 4 | Agogno (NO) | Fluvio-glacial | Sesia-Ticino | sì | | sì |
| 5 | Isola S. Antonio (AL) | Recent alluvional | Po | sì | sì | sì |
| 6 | Borg. S. Martino (AL) | Antique alluvional | Po | sì | sì | sì |
| 7 | Frassineto Po (AL) | Recent alluvional | Po | sì | sì | |
| 8 | Casale (AL) | Recent alluvional | Po | sì | sì | sì |
| 9 | Isola d'Asti | Recent alluvional | Tanaro | sì | | sì |
| 10 | Isola d'Asti | Recent alluvional | Tanaro | sì | | |
| 11 | S. Martino Alfieri | Recent alluvional | Tanaro | sì | | sì |
| 12 | Castagnole Lanze | Recent alluvional | Tanaro | sì | sì | sì |
| 13 | Alba | Recent alluvional | Tanaro | sì | sì | sì |
| 14 | Novi Ligure | Recent alluvional | Scrivia | | | sì |
| 15 | Tortona | Medium-Recent alluvional | Scrivia | | | |
| 16 | Castellazzo Bormida | Recent alluvional | Bormida | sì | | sì |
| 17 | Bosco Marengo | Recent alluvional | Bormida | sì | | sì |
| 18 | Sezzadio | Recent alluvional | Bormida | | sì | |
| 19 | Cassine (AL) | Recent alluvional | Bormida | sì | | sì |
| 20 | Brusasco | Recent alluvional | Po | sì | | sì |
| 21 | Crescentino (VC) | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 22 | Saluggia | Fluvio-glacial | Sesia-Dora Baltea | sì | | sì |

| | | | | | | |
|---|---|---|---|---|---|---|
| 23 | Verolengo | Recent alluvional | Dora Baltea | sì | sì | sì |
| 24 | Torrazza | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | |
| 25 | Villareggia-Rondissone | Recent alluvional | Dora Baltea | sì | | sì |
| 26 | Clavesana | Recent alluvional | Pesio | sì | sì | sì |
| 27 | Magliano Alpi-Farigliano | Medium-Recent alluvional | Tanaro | sì | | sì |
| 28 | Caraglio | Fluvio-glacial | Stura Dem.-Po | | | sì |
| 29 | Caraglio | Fluvio-glacial | Stura Dem.-Po | sì | | sì |
| 30 | Montanera | Recent alluvional | Stura di Demonte | sì | sì | sì |
| 31 | Valle Stura | Recent alluvional | Stura di Demonte | sì | | sì |
| 32 | Salmur | Recent alluvional | Stura di Demonte | | | sì |
| 33 | Greggio | Recent alluvional | Sesia | sì | sì | sì |
| 34 | Biandrate | Recent alluvional | Sesia | sì | sì | sì |
| 35 | Castelletto Cervo | Recent alluvional | Cervo | sì | | sì |
| 36 | Buronzo | Recent alluvional | Cervo | sì | | sì |
| 37 | Envie | Recent alluvional | Po | sì | si | sì |
| 38 | Verzuolo | Recent alluvional | Varaita | sì | | sì |
| 39 | Revello | Recent alluvional | Po | sì | sì | sì |
| 40 | Savigliano | Recent alluvional | Varaita | sì | sì | sì |
| 41 | Scarnafigi | Recent alluvional | Varaita | sì | | sì |
| 42 | Cavallerleone | Recent alluvional | Maira | sì | sì | sì |
| 43 | Faule | Recent alluvional | Po | sì | sì | sì |
| 44 | Cavour | Recent alluvional | Pellice | sì | sì | sì |
| 45 | Osasco | Recent alluvional | Pellice | sì | sì | sì |
| 46 | Ruffia | Recent alluvional | Varaita | sì | sì | sì |
| 47 | Oleggio | Recent alluvional | Ticino | sì | sì | sì |
| 48 | Castelletto Cervo | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 49 | Balocco | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 50 | Trecate | Fluvio-glacial | Sesia-Ticino | sì | | sì |
| 51 | Sozzago | Fluvio-glacial | Sesia-Ticino | sì | sì | sì |
| 52 | Cerrione | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 53 | Mongrando | Recent alluvional | Elvo | sì | sì | sì |
| 54 | Salussola | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 55 | Livorno Ferraris | Fluvio-glacial | Dora Baltea-Po | sì | sì | sì |
| 56 | Palazzo canavese | Fluvio-glacial | Dora Baltea-Po | sì | sì | sì |
| 57 | La Loggia | Recent alluvional | Po | sì | sì | sì |
| 58 | La Loggia | Recent alluvional | Po | sì | sì | sì |
| 59 | Carmagnola | Recent alluvional | Po | sì | sì | sì |
| 61 | Cherasco-Bra | Recent alluvional | Stura di Dem. - Tanaro | sì | sì | sì |
| 62 | Tronzano | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 63 | Borgo d'Ale | Fluvio-glacial | Sesia-Dora Baltea | sì | sì | sì |
| 64 | Rivarolo | Fluvio-glacial | Dora Baltea-Po | sì | sì | sì |
| 65 | S.Maurizio Can. | Fluvio-glacial | Dora Baltea-Po | sì | sì | sì |
| 66 | Caprie | Prasinites | Valle Susa | sì | | |
| 67 | Cartosio | Prasinites | Valle Erro | sì | | |
| 68 | Villanova Mondovì | Dolomites | Valle Ellero | sì | | |
| 69 | Villanova Mondovì | Dolomites | Valle Ellero | sì | | |
| 70 | Bagnasco | Dolomites | Valle Tanaro | sì | | |

Table 2. Los Angeles tests

| N. | Location | Fraction | L.A. | Area and/or Basin |
|---|---|---|---|---|
| 1 | Trecate (NO) | 16-24 | 31 | F.G. Sesia -Ticino |
| 2 | Turbigo (NO) | 8-16 | 25 | Ticino-Sesia |
| 3 | Bellinzago (NO) | 16,31,5 | 36 | F.G. Sesia -Ticino |
| 4 | Agogno (NO) | 8-16 | 33 | F.G. Sesia -Ticino |
| 5 | Isola S. Antonio (AL) | 16-24 | 30 | Po |
| 6 | Borg. S. Martino (AL) | 8-16 | 26 | Po |
| 7 | Frassineto Po (AL) | 16-24 | 30 | Po |
| 8 | Casale (AL) | 16-24 | 26 | Po |
| 9 | Isola d'Asti | 16-24 | 29 | Tanaro |
| 10 | Isola d'Asti | 16-24 | 28 | Tanaro |
| 11 | S. Martino Alfieri | 16-24 | 29 | Tanaro |
| 12 | Castagnole Lanze | 16-24 | 30 | Tanaro |
| 13 | Alba | 16-24 | 29 | Tanaro |
| 16 | Castellazzo Bormida | 8-16 | 21 | Bormida-Scrivia |
| 17 | Bosco Marengo | 16-24 | 16 | Bormida-Scrivia |
| 19 | Cassine (AL) | 8-16 | 23 | Bormida-Scrivia |
| 20 | Brusasco | 16-24 | 30 | Po |
| 21 | Crescentino (VC) | 8-16 | 30 | F.G. Sesia -Dora B. |
| 22 | Saluggia | 16-24 | 30 | F.G. Sesia -Dora B. |
| 23 | Verolengo | 8-16 | 22 | Cervo-Elvo-Dora B. |
| 24 | Torrazza | 8-16 | 29 | F.G. Sesia -Dora B. |
| 25 | Villareggia-Rondissone | 16-24 | 27 | Cervo-Elvo-Dora B. |
| 26 | Clavesana | 16-24 | 28 | Pesio-Stura D. |
| 27 | Magliano Alpi-Farigliano | 16-24 | 28 | Tanaro |
| 29 | Caraglio | 16-24 | 33 | F.G. Stura D.-Po |
| 30 | Montanera | 16-24 | 33 | Pesio-Stura D. |
| 31 | Valle Stura | 8-16 | 32 | Pesio-Stura D. |
| 33 | Greggio | 8-16 | 24 | Ticino-Sesia |
| 34 | Biandrate | 8-16 | 21 | Ticino-Sesia |
| 35 | Castelletto Cervo | 8-16 | 26 | Cervo-Elvo-Dora B. |
| 36 | Buronzo | 16-24 | 22 | Cervo-Elvo-Dora B. |
| 37 | Envie | 16-24 | 20 | Po |
| 38 | Verzuolo | 16-24 | 22 | Maira-Pellice |
| 39 | Revello | 16-24 | 22 | Po |
| 40 | Savigliano | 8-16 | 18,4 | Maira-Pellice |
| 41 | Scarnafigi | 8-16 | 24 | Maira-Pellice |
| 42 | Cavallerleone | 8-16 | 28 | Maira-Pellice |
| 43 | Faule | 16-24 | 31 | Po |
| 44 | Cavour | 16-24 | 32 | Maira-Pellice |
| 45 | Osasco | 8-16 | 24 | Maira-Pellice |
| 46 | Ruffia | 16-24 | 18 | Maira-Pellice |
| 47 | Oleggio | 8-16 | 25 | Ticino-Sesia |
| 48 | Castelletto Cervo | 16-24 | 23 | F.G. Sesia -Dora B. |
| 49 | Balocco | 16-24 | 26 | F.G. Sesia -Dora B. |
| 50 | Trecate | 8-16 | 27 | F.G. Sesia -Ticino |
| 51 | Sozzago | 8-16 | 31 | F.G. Sesia -Ticino |
| 52 | Cerrione | 8-16 | 33 | F.G. Sesia -Dora B. |
| 53 | Mongrando | 8-16 | 32 | Cervo-Elvo-Dora B. |
| 54 | Salussola | 8-16 | 22 | F.G. Sesia -Dora B. |
| 55 | Livorno Ferraris | 16-24 | 35 | F.G. Dora B.-Po |
| 56 | Palazzo Canavese | 16-24 | 30 | F.G. Dora B.-Po |
| 57 | La Loggia | 16-31,5 | 36 | Po |
| 58 | La Loggia | 16-31,5 | 35 | Po |
| 59 | Carmagnola | 8-16 | 37 | Po |
| 61 | Cherasco-Bra | 16-31,5 | 33 | Pesio-Stura D. |
| 62 | Tronzano | 16-31,5 | 27 | Sesia-Cervo |

| | | | | |
|---|---|---|---|---|
| 63 | Borgo d'Ale | 16-31,5 | 24 | Sesia-Cervo |
| 64 | Rivarolo | 16-31,5 | 32 | Dora Baltea-Po |
| 65 | S.Maurizio Can. | 8-16 | 28 | Dora Baltea-Po |
| 66 | Caprie | 9-19 | 15 | Valle Susa |
| 67 | Cartosio | 9-19 | 13 | Valle Erro |
| 68 | Villanova Mondovì | 9-19 | 24 | Valle Ellero |
| 69 | Villanova Mondovì | 9-19 | 18 | Valle Ellero |
| 70 | Bagnasco | 9-19 | 20 | Valle Tanaro |

Table 3. Los Angeles average values referred to homogeneous basins and areas

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

Table 4. Mineralogical analysis: synthesis referred to homogeneous basins and areas

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

Table 5. Petrographical analysis: synthesis referred to homogeneous basins and areas

| Provenienza | Quartz. | Gneiss Granites | Green | Carbon. | Micasc. | Other |
|---|---|---|---|---|---|---|
| Bormida-Scrivia | 7,5 | 16,3 | 53,8 | 22,5 | 0 | 0 |
| Dora B.-Po | 10,2 | 55,3 | 34,5 | 0 | 0 | 0 |
| Cervo-Dora B. | 19 | 47 | 29 | 5 | 0 | 0 |
| Maira-Pellice | 21,4 | 32,9 | 33,6 | 9,29 | 2,14 | 0,71 |
| Pesio-Stura D. | 16 | 57 | 18 | 9 | 0 | 0 |
| Po | 24 | 43 | 29 | 4 | 0 | 0 |
| Tanaro | 32 | 38 | 18 | 10 | 2 | 0 |
| Ticino-Sesia | 11,3 | 66,3 | 17,5 | 5 | 0 | 0 |
| Sesia-Cervo | 10 | 47,5 | 40 | 2,5 | 0 | 0 |
| F.G. Dora B.-Po | 15 | 60 | 25 | 0 | 0 | 0 |
| F.G. Sesia -Dora B. | 21,7 | 40 | 23,3 | 2,5 | 2,5 | 10 |
| F.G. Sesia -Ticino | 11 | 51 | 19 | 2 | 10 | 7 |
| F.G. Stura D.-Po | 15 | 65 | 10 | 10 | 0 | 0 |

## EXPERIMENTAL INVESTIGATION ON AGGREGATES

### Aggregates for mixtures containing scrap tyre rubber

Given the characteristics of available aggregates, the investigation focused on two primary sources of aggregates. Those available in the “Cavaglià” and “Torrazza” quarries. A full characterization was carried out and available size fractions were then checked to be combined in order to satisfy requirements for gap-graded bituminous mixtures. Corresponding results are synthesized in Table 6 and Figure 1.
The investigation was completed by employing available aggregates for the preparation of preliminary gap-graded mixtures with 8.0% binder (containing 18% scarp tyre rubber). Corresponding results are synthesized in Table 7.

Table 6. Optimal combinations of selected aggregates

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

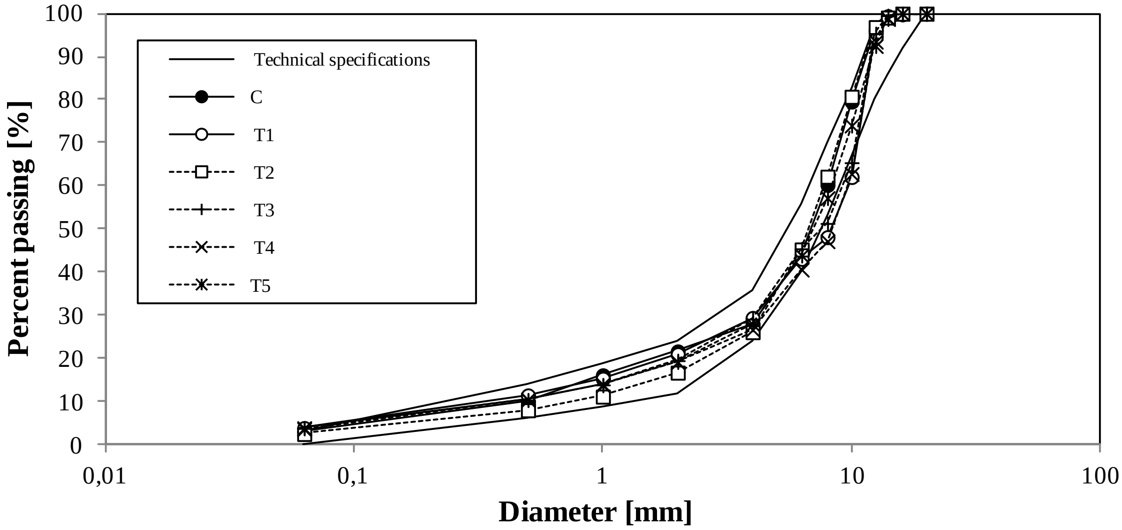


Figure 1. Size distribution analyses of selected aggregates and technical specifications

Table 7. Volumetric and mechanical properties of laboratory-compacted specimens prepared with selected aggregates

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

## CONCLUSIONS

Selected aggregates are totally satisfactory for future experimental and implementation activities.

Further tests will possibly be carried out, when available, on aggregates derived from the new incinerator of the city of Turin.

## PART 2 – INNOVATIVE/RECYCLED AGGREGATES

The investigation on innovative/recycled aggregates focused on the materials obtained from the newly constructed waste incinerator of the City of Torino. As in the case of standard aggregates, they were subjected to characterization tests according to EN standards in the laboratories of "Innovative Road Materials" and of "Environmental Chemistry" of the Politecnico di Torino. An ash-amended rubberized mixture (AARM) was designed by means of the Marshall method and its properties were compared to those of a standard gap-graded rubberized mixture (GGRM, sampled from a traditional plant).

The AARM mixture analyzed in the experimental investigation were produced by employing three different aggregate fractions suitably combined with local MSW bottom ashes (MSW-BA). Mineral aggregates included quartzose sand (0/4 mm) and a metamorphic crushed gravel, supplied in two size fractions (4/8 and 8/12 mm), while the MSW-BA derived from a local waste-to-energy plant. Since the cooling process of ashes is carried out by means of water, MSW-BA was preliminarily dried to remove any trace of moisture. A visual inspection of MSW-BA showed the presence of some coarse metal residues that it had been necessary to remove manually since they could have affected the mixing operations with the binder. The final ash gradation contained sizes up to 16 mm.

The combined aggregate gradation, and thus the MSW-BA content, of AARM mixtures was defined according to technical specifications commonly adopted in Italy for rubberized gap-graded mixtures and it is shown in Table 1 and Figure 1, in which is also reported the GGRM aggregate distribution. The GGRM reference mixture was sampled from a traditional plant and it was produce with the same aggregate distribution, same asphalt rubber employed for the AARM and with a binder dosage of 8.5%.

Table 1. AARM aggregate composition

| Aggregate type | Percentage [%] |
|---|---|
| 0/4 | 17 |
| 4/8 | 37 |
| 8/12 | 25 |
| MSW-BA | 21 |

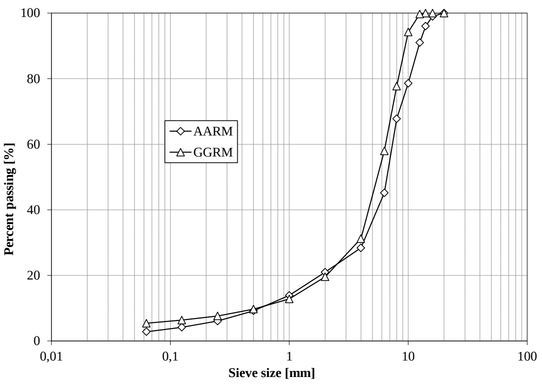


Figure 1. Job-mix formula gradation of AARM and GGRM

Mix-design was carried out by means of Marshall method by varying the binder content within the range 7.0-9.0% (by weight of dry aggregates), increasing the binder quantity by 0.5% each time. As previously reported, due to the high surface area of ashes (which absorbed a large amount of bitumen) a reduction of the effective binder has been observed and, because of this, mixtures with lower binder content have revealed a not satisfactory degree of coating of aggregate grains. For this reason, mixtures prepared with 7 and 7.5% of asphalt rubber were discarded by the experimental investigation. For each of the remaining mixtures, 4 specimens were prepared and compacted by means of the Marshall hammer with 75 blows per side.

The average results of volumetrics and Marshall properties are listed in Table 2, in which theoretical maximum density (TMD), air voids content (v), voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), stability (S), flow (f) and Marshall quotient (MQ) are shown. Due to acceptance limits, results leads to an optimum binder content of 9.0%.

Table 2. Volumetric and Marshall properties average values of AARM mixtures

| Blend | Binder content [%] | TMD [kg/m$^3$] | v [%] | VMA [%] | VFB [%] | S [kN] | f [mm] | MQ [kN/mm] |
|---|---|---|---|---|---|---|---|---|
| AARM_8.0 | 8,0 | 2433 | 8,5 | 24,6 | 65,6 | 9,3 | 3,4 | 3,3 |
| AARM_8.5 | 8,5 | 2420 | 8,3 | 25,3 | 67,3 | 9,4 | 3,8 | 2,6 |
| AARM_9.0 | 9,0 | 2378 | 6,0 | 24,0 | 75,4 | 9,8 | 3,8 | 2,8 |

## RESULTS AND DISCUSSION

Results derived from Marshall test are listed in Table 3 which also contains values of volumetric properties.

Table 3. Volumetric and Marshall properties average values of AARM and GGRM

| Blend | Binder content [%] | TMD [kg/m$^3$] | v [%] | VMA [%] | VFB [%] | S [kN] | f [mm] | MQ [kN/mm] |
|---|---|---|---|---|---|---|---|---|
| AARM | 9,0 | 2378 | 6,0 | 24,0 | 75,4 | 9,8 | 3,8 | 2,8 |
| GGRM | 8,5 | 2540 | 6,9 | 24,5 | 71,9 | 7,1 | 2,7 | 2,6 |

As expected, as a consequence of the higher binder dosage AARM mixture was characterized by lower void content and higher VFB values than GGRM mixture.

Referring to Marshall properties, a first observation was drawn by comparing the Marshall stability. The ash-amended rubberized mixture showed a significantly higher value compared to the reference one (+38%). Such an increase can be explained assuming that the combined effects of the interaction of fine part of ashes with binder matrix and the shape of coarser ones originated an internal structure with higher strength. However, the stiffness of AARM mixture (expressed in term of Marshall Quotient) was not affected by the addition of ashes. At first, this could be attributed to increased binder dosage but, as shown in the Table 2, similar flow values have been recorded even for the lower binder contents. It can be assumed that the presence of ashes led to an increase of the flow value probably due to an enhancement of the ductility properties of the mixture (and related to the chemo-physical properties of ashes employed and their interaction with the asphalt rubber).

## CONCLUSIONS

The analysis of obtained results revealed that the interaction of ashes with the asphalt rubber and the aggregate skeleton greatly increased the Marshall stability. Nevertheless, the Marshall Quotient, which allows to have information about the stiffness of mixtures, remains almost constant due to the enhancement of the ductility properties of the mixture.

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