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Effects of chemical admixtures on the rheology of fresh recycled aggregate concretes

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HIGHLIGHTS

- Fresh behavior of recycled concrete is analyzed.
- The effects of using plasticizer and air-entrainer in concrete are studied.
- Bingham parameters are estimated to assess the rheological behavior of the batches.
- Rheographs are used to study the rheological behavior of the mixes.

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ABSTRACT

Air-entrainers and super-plasticizers are among the most used chemical admixtures that affect the rheological parameters of fresh cement-based materials. In this work, their influence on fresh properties of recycled aggregate concrete (*RAC*) is investigated through an experimental campaign, where Bingham rheological parameters, i.e. plastic viscosity μ and yield stress τ_0, were analyzed. Ten concrete mixtures were prepared, varying w/c ratio, admixtures content, recycled coarse aggregate substitution ratio and aggregates proportioning methods. In this regard, a particular attention was paid on the Equivalent Mortar Volume (*EMV*) method for *RAC* designing. Results were then compared to ones obtained in a previous experimental campaign carried out by the same authors, where further twenty concretes were prepared with the same materials and under the same conditions. From the results achieved in this work, it is possible to conclude how the admixtures addition and aggregates proportioning method influence yield stress and plastic viscosity values.

1. Introduction

In the last two decades, many studies have analyzed the effects of substituting natural aggregates (*NAs*) with recycled ones to produce structural concrete, focusing mainly on aspects related to mechanical strength and durability. A huge literature exists about this topic [1–5], due to the great interest to reduce environmental impacts of the construction industry [6], answer to the rising problem of local depletion of natural resources [7] and limit the soil consumption destined both to landfilling of inert materials and mining [8]. In Europe, the impact of this productive sector has been such that the Member States developed new standards and guidelines that go towards an integral sustainable development, aiming at reaching the well-known *H2020* objective of recycling at least the 70% of non-hazardous construction and demolition waste (*C&DW*). However, the current situation about inert material recycling is still far from the stated objectives, at least in some States. A mix of co-causes, including regulation barriers, large availability and low cost of virgin resources, and poor quality of *C&DW* separating techniques, are responsible for a limited use of recycled aggregates (*RAs*) in civil engineering applications, and mainly in structural concrete [9].

In spite of the great availability of experimental evidences about mechanical and durability-related properties of hardened recycled concretes, few studies exist about the influence of *RAs* on fresh concretes workability and rheology. A well-known effect of *RA* use on workability is a drop of the slump value, which can be easily overcome using water-reducing admixtures (*WRA*) in

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the mixes [10], or through mix design procedures mainly aimed at pre-saturating the recycled aggregates before their use [11–14]. Several works [15,16] experimentally confirmed this workability loss, which is directly related to the high water absorption, porosity and rough texture of the *RA*s. A remarkable evidence of this phenomenon is obtained when a particular aggregate proportioning method is used, called Equivalent Mortar Volume (*EMV*) method. The methodology, originally proposed by Fathifazl et al. [17], and also validated by other research works [18–20], is based on the quantification of attached mortar (*AM*) on original aggregates composing the *RA*, which is hence seen as a two-phase material. The method aims to take into account the old *AM* content in the mix design, thus reducing the overall cement dosage necessary to produce a concrete exhibiting the same strength and durability as those of the reference, containing *NA* alone [21]. In spite of the comparable strength attained by *RACs*, prepared with the *EMV* method, when compared to the control, workability and rheology are negatively affected, due to few amount of fresh mortar available in the batches. This problem was initially observed by Knaack and Kurama [22], who studied the rheology of *RAC* designed with direct weight replacement (*DWR*), direct volume replacement (*DVR*), and *EMV* methods through the so-called mini-slump test [23]. Then, Faleschini et al. [24] analyzed for the first time the rheological properties of *RAC*s prepared with various aggregate proportioning methods, including the *EMV*, through a viscometric campaign aimed to experimentally assess Bingham parameters. Severe slump drop was observed in concretes prepared with the *EMV* method, with also an increase of the yield stress τ_0; however, they may be both reduced by increasing the quantity of *WRA* in the mix. Nevertheless, this operation was not sufficient to allow rheological behavior similar to that of *NAC* and *RAC* proportioned with conventional methods, although the same slump values could be reached, due to a negative effect on plastic viscosity μ.

Recently few other works studied the rheological behavior of concretes including *RA*s. Mohamed Amer et al. [11] investigated the influence of saturation condition of coarse *RA* on Bingham parameters, and observed that the use of pre-saturated aggregates is more effective in reducing the values of τ_0 and μ than the addition of high quantities of super-plasticizer (*SP*). Kebaïli et al. [25] attempted to produce self-compacting concrete (*SCC*) with various *RA* contents, using *DWR* aggregate proportioning method and aggregates in dried condition; regardless the substitution ratio, they were not able to achieve the target objective, i.e. to design *SCC*, as the replacement implied an increase in the rheological parameters not compatible with *SCC* requirements. Carro-López et al. [26] and Güneyisi et al. [27] studied the rheological behavior of *SCC* with *RA*s, which were used also as fine aggregates. Even though in both cases the *RAs* were pre-saturated for a certain time before their use, disagreeing results were achieved; in the former work, the high water absorption of fine recycled sand induced a removal of free water in the mix, thus leading to a quick deterioration of the SCC properties in a time period depending on the amount of the substitution. Better results were achieved in the latter, where the flowability increased with the fine RA content.

According to the available literature, the effect of chemical admixture use on rheological parameters of vibrated *RAC* is not well investigated yet. Particularly, a positive influence of *SP* on both natural and recycled concretes is well-known, even if designed with the *EMV* method, as observed by the authors in a previous study [24]; still in this case, plastic viscosity is not comparable to that of conventional batches. Accordingly, in this work the effects of the use of both air-entraining admixture (*AEA*) and *SP* on fresh rheological properties of natural and recycled concretes, proportioned with the *DVR* and *EMV* methods, are experimentally investigated.

2. Materials and methods

2.1. Materials

The same materials used in Faleschini et al. [24] were employed in this experimental campaign. A natural sand (maximum grain size of 4 mm) and two coarse crushed aggregates were utilized (maximum grain size of 12.5 mm), one natural and one recycled coming from a local recycling of *C&DW* plant sited in the northern region of Spain. *RA* is obtained mainly from demolition of concrete structures, being a recycled concrete aggregate (*RCA*). All aggregates comply with the limit requirements for sulfur total compound (<1%), acid soluble sulfates (<0.8%) and chlorides content (<0.05%) established in the Spanish Code for Structural concrete [28]. Natural sand and gravel are mainly constituted by calcite, whereas the *RCA* is more heterogeneous, being constituted by quartz and calcite, other than the cement phases present in the attached mortar, e.g. calcium silicate hydrate, portlandite, Afm, Aft, and ettringite. Concerning aggregates physical characteristics, their density (apparent, oven-dry, saturated-surface dry condition and bulk dry-rodded) and water absorption are listed in Table 1. In the same table, the estimated quantity of *AM* is reported for *RCA*; this value has been experimentally assessed through a thermal attack methodology. The *RCA* composition is made of 37% of original clean *NA*, 59% of concrete and mortar compounds, and 4% of residual bituminous material. Fig. 1 shows instead the grading curve of the aggregates.

A cement type *CEM I 52.5R*, with high clinker content (>95%), high strength and rapid setting has been used. Two commercially available admixtures were chosen: a polycarboxylates-based *SP* and an *AEA*. Lastly, tap water was added in the mix.

2.2. Concrete design and mixing procedure

The objective of this work is to identify the influence of *SP* and *AEA* admixtures on rheological properties of fresh recycled concretes, also using the results obtained in a previous work of the authors [24]. For sake of completeness, the mix details (per m^3 of concrete) of the previous campaign are reported here, in Table 2. This first group contains 20 mixtures, which were designed to achieve a *S4* consistency class for mixes with a *w/c* of 0.4 and 0.5, with target strength classes of f_{ck} = 50 MPa and f_{ck} = 40 MPa, respectively. Four conventional concretes, eight *RAC* designed through *DVR* method and eight *RAC* designed with *EMV* method constitute the first set of mixes. The aggregates replacement ratios were 20% and 35%, and for all the batches a *SP* admixture was used, with two dosages. The amount of *SP* was chosen in order to allow the concretes reaching almost the same slump value. The name of each concrete indicates: the mix proportion method and the aggregates substitution ratio/the w/c ratio – the *SP* dosage expressed in percentage of cement content. Table 2 lists the 28-days compressive strength values for each concrete, also. This value indicates the average of at least three tests of cylindrical specimens with dimension $d \times h$ = 100 × 200 mm. Standard deviation value is reported as well.

The second group of concretes is made instead by 10 fresh batches (Table 3), which were designed closely following the same proportions of the previous ones, but using only one dosage of *SP* (the lowest), and adding a fixed amount of *AEA*. The name of each concrete indicates in this case: the mix proportion method and the aggregates substitution ratio/the w/c ratio – the *SP* dosage – the *AEA* dosage, the latter two both expressed in percentage of cement content. The 28-days compressive strength values are listed in Table 3 for each mix. Also in this case, f_c value indicates the average of at least three tests of cylindrical specimens with dimension $d \times h$ = 100 × 200 mm. The value of standard deviation is reported in Table 3 as well.

The utilization of the *EMV* method for concrete designing implies important reductions of the mortar contents if compared to the *RAC* proportioned with the conventional method, as it can be seen from both Tables 2 and 3. This is due to the principles of the method, since *AM* is accounted as a part of the total mortar needed by design the mix, which allows concrete structure to be comparable to that of *NAC*, at least in terms of each component volume, and potentially also in terms of mechanical strength. Conventionally designed *RAC* are characterized instead by excessive amount of mortar, when counting the new one and the one attached to the *RA*, thus it is reasonable to assume that they will result in worse performances than the *EMV*.

The same mixing procedure and almost the same temperature and humidity conditions were maintained in the two experimental campaigns. This is due to the fact that workability and rheology of fresh concretes can be highly affected by environmental conditions and time. Before mixing, the aggregates were dried at 100 ± 5 °C for 24 h; then, they were weighted and placed inside individual hermetic closing drums, together with the absorption water, for further 24 h. After this, and also right before mixing, they were intensively agitated in order to guarantee a uniform distribution of the absorption water within the aggregates. Then the mixing and testing procedure shown in Fig. 2 was applied to each mix.

2.3. Experimental evaluation of rheological parameters

After 9 min of mixing from the first addition of water, the slump test was performed for each mixture through the Abrams cone method, which is the most simple, fast and cost-effective procedure to study concrete's flowing characteristics.