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Cement and Concrete Research 35 (2005) 836–841
Cement and Concrete Research

# Evaluation of mixing and application process parameters of single-coat mortars

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Received 12 May 2004; accepted 21 October 2004

**Abstract**

The effects of different preparation and application conditions of single-coat mortars in their characteristics as fresh and hardened products are described in this work. The parameters under consideration were mixing water, mixing and resting time of the fresh mortar. Tests were made in the fresh mortar like apparent density, amount of entrained air and water retention. Tests with the hardened mortar also included mechanical strength and capillarity evaluations. Finally, practical cases were considered and here some application parameters were studied. It was possible to conclude on some important parameters affecting both the processing and application of single-coat mortars.


*Keywords:* Mixture proportioning; Workability; Characterization; Physical properties; Bending and compressive strength; Single-coat mortar

## 1. Introduction

Rendering/plastering mortars are usually divided into conventional and "single-coat" systems [1]. Conventional "multi-coat" systems begin with an under-coat mortar, which fulfils the technical requirements (e.g. mechanical strength, levelling), and end with a finishing mortar that guarantees weatherproofing and the aesthetic demands (e.g. colour, texture). In "single-coat" systems, a designed rendering mortar is applied directly over the brickwork in a single coat, which fulfils both functional and aesthetic functions.

Single-coat or single-layer renders can be classified as non-traditional mortars based on a mixture of inert, cement, lime and some specific additives able to grant some required properties regarding the product either in the fresh or hardened state. Amongst them, the air entraining agents are used to introduce and disperse air bubbles into the mortar paste during the kneading process. This increases the mortar workability and can even reduce the amount of kneading water. They can even render the mortar impermeable if the air bubbles cut the capillary network. Regarding the application, these additives can improve its efficiency since the mortar becomes lighter. At the same time, their presence can also reduce some mechanical properties like elastic modulus and flexure or compression strength [2–4].

These single-coat mortars are usually prepared in a factory and its use can be resumed to the mixing of the right amount of water and the kneading process to obtain the proper consistency for the application of the fresh product. The application can be made manually or automatically by projection equipments working in a continuous or a discontinuous mode. In any case, the effect of parameters like kneading water amount, mixing and resting time should be considered [5]. It is well known the influence of water and related amount of voids created in the mechanical properties [6,7]. On the other hand, mortar application in continuous projection equipments can hardly respect mixing and resting times which altogether can injure the final result [8,9].

In the specific cases of mortars containing air entraining agents, mechanical kneading should respect recommended mixing and resting times in order to reach the desired

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0008-8846/$ - see front matter 
doi:10.1016/j.cemconres.2004.10.026

amount of included air and obtain the adequate workability [10]. For instance, excess mixing time can introduce air in excess resulting in poor mechanical strength. On the contrary, a short mixing time (included air deficiency) results in a compact material with a very high elastic modulus [11]. The same happens with excessive resting times, originating denser mortars. It is also often observed in mortars, with air-entraining agents, a large deficit in cohesion due to excess inclusion of air during kneading, due to excess use of water and mixing times [12]. In general, the effects of processing parameters (e.g., kneading water, mixing and resting time) and chemical admixtures such as air-entraining agents are well documented [13–16] and overall tendencies well defined mostly for cement and concrete. However, particular processing conditions of mortars might impose deviations to those general tendencies and deserve also a careful definition. In this work, it is attempted to elucidate these relationships by evaluating the effect of parameters like mixing and resting time, kneading water and type of equipment over the properties of fresh and hardened single-coat mortars.

## 2. Experimental

The mortar sample used in this work is typical for single-coat render applications. Its cement/sand ratio is 1:6.5, being the cement used of the type Portland I, 52.5N White (Secil, Portugal). Small traces of cellulosic ether (<1 wt.%) are used as workability additive. It can be characterized according to the MERUC classification, established by CSTB as patented in Table 1 [17–19]. Accordingly, the used product can be considered as semi-heavy, close to the characteristic values of a light material [17]. About its constitution, it should be referred that it also contains an air-entraining agent based on a sodium sulphonate olefin (Clariant) (≈0.17% of the cement amount).

Characterization of the behaviour of the single-coat mortar was performed trough measurements of properties of this product in the fresh and hardened state. In the first case, it involved the determination of apparent density, included air and water retention while for the hardened product it involved the determination of apparent density, dynamic elastic modulus, mechanical strength (flexure and compression) and capillary coefficient. For characterization of the hardened mortar, a total of 10 samples with dimensions of 4×4×16 cm plus five samples with 2.5×2.5×28.5 cm were prepared in metallic moulds. All the characterization of these properties was made in accordance with standard tests (EN 1015).

Table 1
MERUC characterization of used single-coat mortar

| Symbol | Property | Classification MERUC [5] |
|---|---|---|
| M | Apparent density | $M_3$ |
| E | Dynamic elastic modulus | $E_3$ |
| R | Flexural strength | $R_3$ |
| U | Water retention | $U_5$ |
| C | Capillarity coeficient | $C_1$ |

Table 2
Correspondence between the percentage of kneading water and w/c ratio in the mortar

| $H_2O$ (%) | w/c |
|---|---|
| 18 | 1.20 |
| 19 | 1.27 |
| 21 | 1.40 |
| 23 | 1.53 |
| 25 | 1.67 |

Processing parameters under evaluation were kneading water content, mixing and resting time of the fresh mortar. Regarding the kneading water, products were prepared covering from difficult workability (compact) conditions until a fluid mortar due to excess water. Table 2 gives the correspondence to the w/c notation. Regarding the missing time, this parameter was varied from 30 to 300 s, after which the fresh mortar was immediately analysed. Finally, the resting time of the fresh mortar was changed between 0 and 3600 s and characterization cited above for fresh mortar was also performed.

Concerning mortar application parameters evaluation, three distinct situations were analysed:

(i) Single-coat mortar mixing and application by projection with discontinuous mode equipment (Putzmeister SP11). Fresh and hardened mortar was first evaluated with a kneading water content of 21%, a mixing time of 300 s and a resting time of 180 s. These last variables were also changed for evaluation purposes.
(ii) Single-coat mortar mixing and application by projection with continuous mode equipment (*Duo Mix Plus*). Characteristics of fresh and hardened mortar were measured under a flow of kneading water of 470 l/h. Regarding mixing and resting time, they were kept constant due to the equipment operation conditions.
(iii) Single-coat mortar mixing in a concrete mixer and manual application. Kneading water was also 21% and mixing and resting times were kept constant at 300 and 120 s, respectively.

## 3. Results and discussion

### 3.1. Processing parameters

#### 3.1.1. Kneading water

Apparent density and included air content are shown in Fig. 1 for mortars with different kneading water amounts. It is possible to observe that an increase of water up to 24% corresponds an increase in entrained air. More water in the kneading process causes an inversion in this relation due to loss of consistency of the fresh mortar.

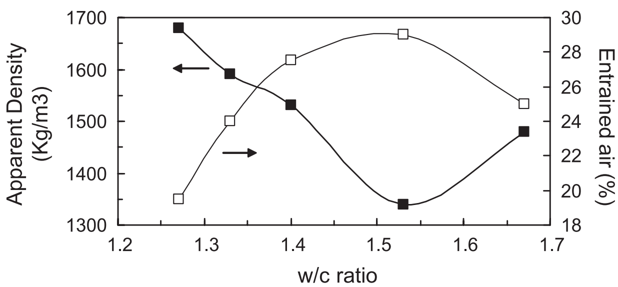


Fig. 1. Effect of the amount of kneading water (expressed as w/c ratio) on the apparent density and amount of included air of the fresh mortar.

As a consequence of the air inclusion in the mortar, the apparent density values changes with kneading water in the opposite way [13].

Fig. 2 shows the variation of water retention in fresh mortars also as a function of kneading water. There is a significant decrease of water retention with increasing water content that leads even to a change in the MERUC classification [17] of the fresh mortars. If it is not taken into account, this can cause an application problem related to the mortar working time after deposition in the wall.

Regarding the effect of kneading water in the hardened product characteristics, Table 3 shows the variation in apparent density, shrinkage and capillary coefficient, while Figs. 3 and 4 shows the variation in mechanical properties (flexure and compression strength; elastic modulus), indicating also the mortars MERUC classification. From this set of results, it can be said that hardened mortar characteristics were affected by kneading water amount. More detailed information is given elsewhere [20]. Shrinkage strongly increases reaching values above 1.2 mm/m, which according to CSTB classification represents materials with a high tendency for cracking [17]. As should be expected, apparent density clearly decreases due to the increase of voids generated by the presence of water. They are also important in the observed increase in the capillarity coefficient of those mortars. Particular consideration should be taken

Table 3
Effect of kneading water on hardened mortar characteristics

| w/c ratio (%) | Apparent density (kg/m$^3$) | Shrinkage (mm/m) | C ($\times 10^{-3}$) (kg/m$^2$ s$^{1/2}$) |
|---|---|---|---|
| 1.27 | 1510 | 1.000 | 2.84 |
| 1.33 | 1450 | 1.016 | 3.10 |
| 1.40 | 1350 | 1.044 | 3.35 |
| 1.53 | 1220 | 1.090 | 4.26 |
| 1.67 | 1280 | 1.150 | 5.68 |

concerning the variation on their mechanical properties (Figs. 3 and 4). A strong decrease is observed in mechanical strength and elastic modulus with increasing kneading water content. Furthermore, the variation is such that the results can even take three different MERUC mortar classes [19]. If, in one side, there is a case of excess water that leads to mortars with weak mechanical strength, which can have associated problems of cohesion during application, on another hand, there are also mortars with a deficit in

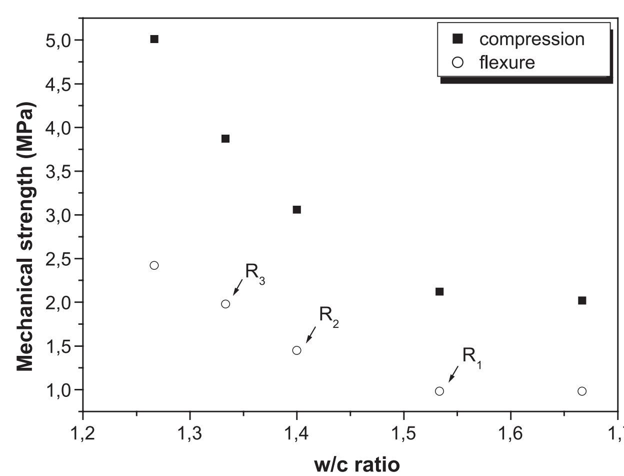


Fig. 3. Variation of mechanical strength (flexure and compression) with the amount of kneading water (expressed as w/c ratio). MERUC classification is also indicated.

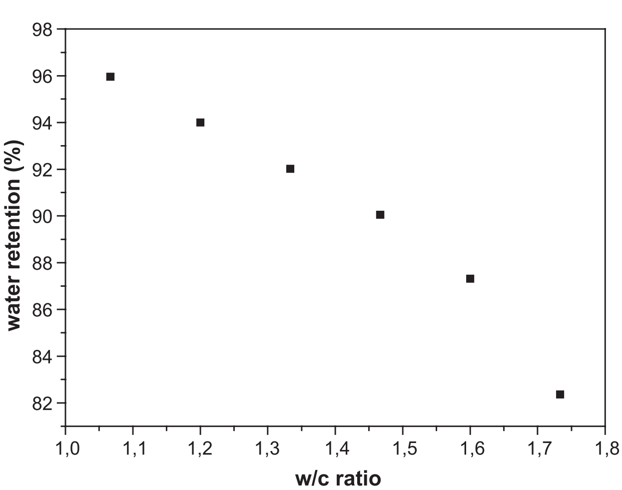


Fig. 2. Effect of the amount of kneading water (expressed as w/c ratio) on the water retention of fresh mortar.

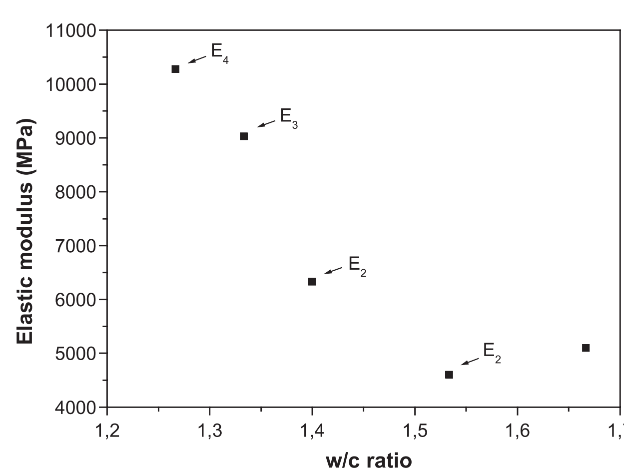


Fig. 4. Variation of elastic modulus with the amount kneading water (expressed as w/c ratio). MERUC classification is also indicated.

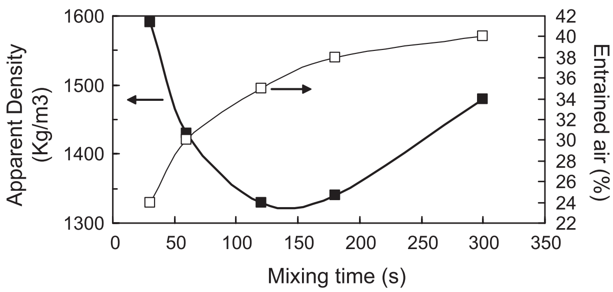


Fig. 5. Effect of the mixing time on apparent density and amount of included air of the fresh mortar.

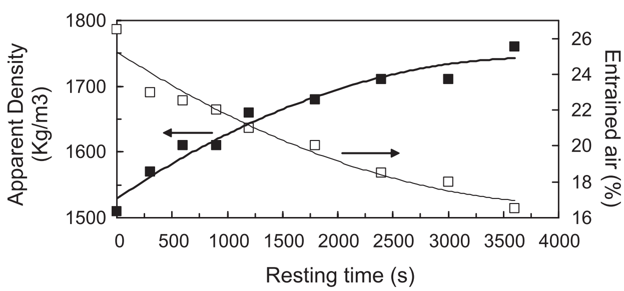


Fig. 6. Effect of the resting time on apparent density and amount of included air of the fresh mortar.

kneading water, causing lower entrained air amounts and, hence, resulting in a heavy material with probable problems of mechanical incompatibility with the support.

### *3.1.2. Mixing time*

Evaluation of mixing time was only done on the characteristics of the fresh mortars, namely, in the apparent density and entrained air amount. The kneading water amount was set at 21% and the results are indicated in Fig. 5. An increase of the mixing time leads to a higher amount of entrained (or included) air in the fresh mortar, with corresponding decrease on apparent density [15]. For mixing time higher than 5 min there is, in this composition, a clear separation of binder and inert materials, which makes difficult the production of homogeneous mortars.

Table 4
Characteristics of the mortar applied with a discontinuous projection equipment

| | Property | MERUC class |
|---|---|---|
| *Fresh mortar* | | |
| Apparent density (kg/m$^3$) | 1610 | – |
| Included air (%) | 22.0 | – |
| *Hardened mortar* | | |
| Apparent density (kg/m$^3$) | 1448 | $M_3$ |
| Compression strength (MPa) | 3.05 | – |
| Flexure strength (MPa) | 1.78 | $R_3$ |
| Elastic modulus (MPa) | 6850 | $E_4$ |
| Capillarity coefficient (kg/m$^2$ s$^{1/2}$) | $3.87\times10^{-3}$ | $C_1$ |

Table 5
Characteristics of the mortar applied with a continuous projection equipment

| | Property | MERUC class |
|---|---|---|
| *Fresh mortar* | | |
| Apparent density (kg/m$^3$) | 1760 | – |
| Included air (%) | 15.0 | – |
| *Hardened mortar* | | |
| Apparent density (kg/m$^3$) | 1620 | $M_4$ |
| Compression strength (MPa) | 4.70 | – |
| Flexure strength (MPa) | 1.75 | $R_3$ |
| Elastic modulus (MPa) | 11 400 | $E_4$ |
| Capillarity coefficient (kg/m$^2$ s$^{1/2}$) | $5.42\times10^{-3}$ | $C_1$ |

Table 6
Characteristics of the mortar after manual application by mixing in a concrete mixer equipment

| | Property | MERUC class |
|---|---|---|
| *Fresh mortar* | | |
| Apparent density (kg/m$^3$) | 1600 | – |
| Included air (%) | 24.0 | – |
| *Hardened mortar* | | |
| Apparent density (kg/m$^3$) | 1400 | $M_3$ |
| Compression strength (MPa) | 3.12 | – |
| Flexure strength (MPa) | 1.80 | $R_3$ |
| Elastic modulus (MPa) | 6800 | $E_3$ |
| Capillarity coefficient (kg/m$^2$ s$^{1/2}$) | – | – |

### *3.1.3. Resting time*

Also in this case, the effect of resting time was evaluated on the fresh mortar characteristics (apparent density and entrained air) and it is presented on Fig. 6. The increase of resting time after the kneading or mixing process originate a gradual decrease of the entrained air in the fresh mortar and a consequent increase in its apparent density. Hence, it has the opposite effect of mixing time and, as before, in terms of practical effects, the arguments are the same as indicated for the kneading water influence.

## *3.2. Application parameters*

Three basic practical situations related to mortar application process were studied and the mixing effects were

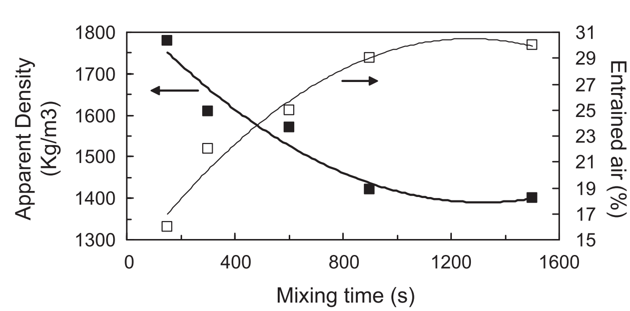


Fig. 7. Effect of the mixing time during application with a discontinuous projection equipment on apparent density and amount of included air of the fresh mortar.

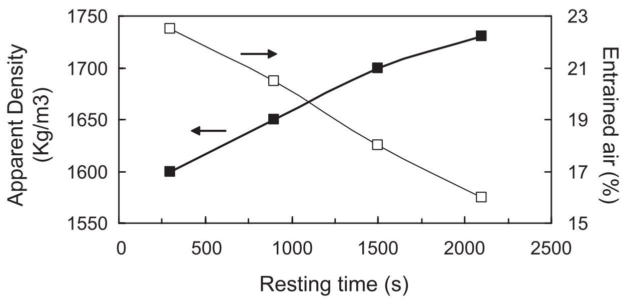


Fig. 8. Effect of the resting time during application with a discontinuous projection equipment on apparent density and amount of included air of the fresh mortar.

evaluated. As stated before, these included (a) mixing and projection in a discontinuous way; (b) mixing and projection by a continuous process and (c) mixing with a concrete mixer and manual application. The results are presented in Tables 4–6 for the three cases (a, b and c), respectively. In these tables, the MERUC classes [17] of the produced mortars are also indicated. Finally, Figs. 7 and 8 show the effect on mixing and resting time in a situation where the discontinuous projection equipment was used.

Overall analyses of these results immediately show that they can strongly determine the properties of the mortar single-coatings. For instance, Table 5 reveals that a continuous mode projection, which have associated quick mixing and application times (typically 30 s), does not allow an adequate air inclusion which results in higher apparent density values of the fresh mortar. It also increases significantly the mechanical properties, namely the elastic modulus (changing it for a $E_4$ class material). On the other hand, using of equipments like the discontinuous projection equipment or the concrete mixer allow the proper development of air inside the fresh product which results on adequate recommended values for the materials properties, as can be observed in Tables 4 and 6. Figs. 7 and 8 show that mixing and resting times can also influence negatively the fresh mortar properties, in terms of apparent density and amount of included air. As a consequence, hardened product characteristics are also affected.

## 4. Conclusions

A set of parameters related to mixing and application of single-coat mortars can influence the properties of fresh and hardened products, particularly if the material contains air-entraining agent in its composition. From this set, kneading water amount, mixing and resting time were process parameter evaluated in this study. All of them can decisively change the included air in the fresh state in such way that significantly alters the properties of the coating, as observed several times by the change in the MERUC classification of mortars. Associated with these changes, the process can be further hindered when they interfere with indispensable requirements of a good single-coating such as, cohesion and mechanical strength, compatibility with the support or resistance to cracking.

Application related parameters were also evaluated. Mixing and application equipment and mode should be carefully chosen in order to prevent any damage to the final coating mortar properties. A continuous projection machine is not advisable since it drastically reduces mixing and resting times, causing inability of introducing the right amount of voids in the fresh mortar by the air-entraining agent. On the other hand, it was observed that a discontinuous projection machine or a concrete mixer followed by manual application are trustful options because they allow enough time to the introduction of air in the fresh product. Besides this, they make it easy any compensation action in case of excess air introduction, because they also allow enough resting time to the mixed material. It must be realized that the existence of all these variable parameters can lead to single-coat mortars with different behaviours and the need to control it to avoid future problems.

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