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Short Communication

Mechanical properties of steel fibre reinforced and rubberised cement-based mortars

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ABSTRACT

Previous studies demonstrated that crack cutting bonded cement-based repairs is highly detrimental to the durability of such applications. Laboratory tests and field experience showed that fibre reinforcement allowing the control of the crack opening and assuring the structural continuity is a solution to enhance the durability of bonded cement-based repairs. In other respect, recent work pointed out that the use of rubber aggregates obtained from grinding end-of-life tyres is a suitable solution to improve the strain capacity of cement-based materials. The present contribution focuses on the synergetic effect of rubber aggregate incorporation and of fibre reinforcement from the point of view of the use of the composite in the repair work application.

Effects of fibre reinforcement, of rubber aggregates incorporation and of their association are evaluated by comparing the mechanical response of the cementitious mortars in which they are used to the one of the control mortar. Fibre reinforced and/or rubberised cement-based mortar were cast using 20% and 30% by volume of rubber aggregates replacing mineral aggregates. To control the crack as soon as possible, a type of high bond steel fibre was selected in this study and contents of 20, 30, 40 kg/m^3 have been used. Direct tensile tests were firstly conducted to obtain the tensile strength, the straining capacity and the residual post peak behaviour. Compressive strength and Young's modulus were determined from compressive tests. Results showed that despite rubber incorporation was detrimental to the material strength (compressive and tensile strengths) and reduced the modulus of elasticity, the strain capacity was enhanced. Results obtained on steel fibre reinforced and rubberised cement-based mortars (SFRRM) pointed out a positive synergetic effect: it is noted that one can make profitable the effects of rubber aggregates (high strain capacity) and those resulting from the fibre reinforcement (significant residual post peak strength) to get an interesting behaviour when resistance to cracking is a priority.

1. Introduction

For large concrete areas, the technique of thin bonded cement-based overlays is very widespread and proves to be effective [1–3]. However, up to now, such repairs have sometimes posed a problem because of their hazardous durability. It remains a demand to control their behaviour and to find solution to ensure their durability. Major problems, such as cracks and interface debonding, may occur after a period in service. As sketched on Fig. 1, the durability of thin bonded cement-based overlays is compromised by the cracking of the repair layer followed by its debonding from the substrate [1,4]. Two debonding mechanisms and their combination are considered: on the one hand the loads applied on the overlaid structure, on the other hand the different length changes of the overlay and of the base structure, especially because of the higher shrinkage of the overlay made of new concrete or mortar. According to previous numerical studies, it appears that the use of overlay materials having high tensile strength makes it possible to reduce the risk of cracking [5]. Moreover, if the overlay material had a low Young's modulus, it would give an additional advantage by conferring a high strain capacity delaying the crack localisation, particularly cracking due to restrained shrinkage that results from the differential length change between the substrate base and the overlay [5]. Unfortunately, it is well known that this ideal, namely low modulus and high strength are two characteristics mutually exclusive.

The incorporation of metallic fibres in a mortar has proven to improve several of its properties, mainly their ductility. Laboratory tests and field experience showed that the reinforcement of the overlay by fibres, providing some continuity through the cracks, delays debonding initiation and its propagation [1,3,6]. Reinforcing steel bars or welded wire fabric could also be considered beneficial but they are only usable having a thick overlay with respect to cover depth requirements. Another advantage of fibres is that, contrarily to steel bars, they present reduced risk of corrosion [7].

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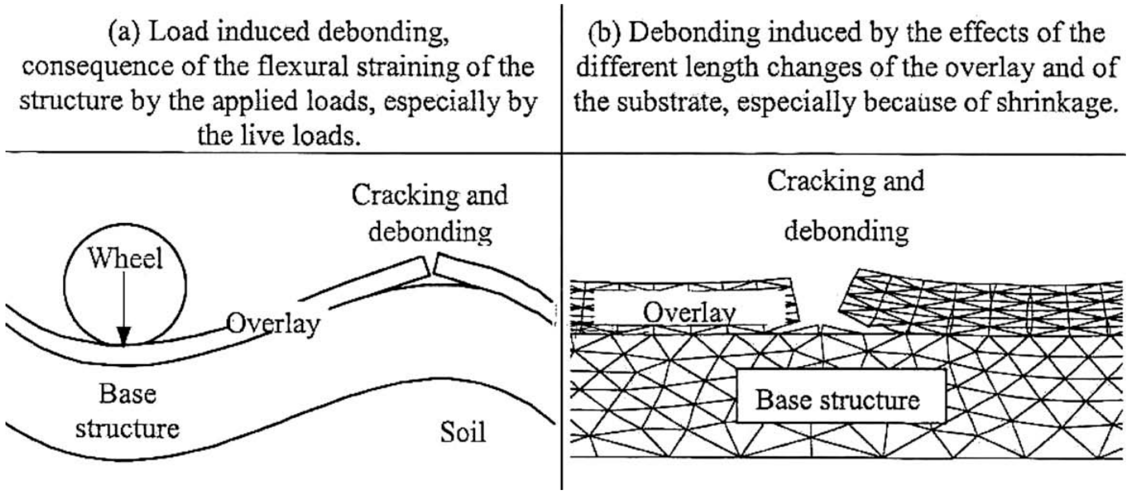

Fig. 1. Debonding mechanisms: (a) Debonding induced by the load and (b) Debonding induced by the effects of the different length changes.

From mechanical approaches and environmental perspective, the properties of concrete incorporating rubber aggregates obtained from grinding end-of-life tyres has been widely studied [8–12]. Despite a detrimental effect on the material strengths, the reduced modulus of elasticity of rubberised cement-based material is expected to improve the strain capacity. The objective of this paper is to evaluate the mechanical properties of a composite mortar incorporating rubber aggregates and steel fibres, in particular their positive synergetic effect for repair applications. The involved mechanical properties in the durability of repairs are the compressive, tensile strengths, the Young's modulus and the softening behaviour.

2. Experimental programme

2.1. Materials and mix proportions

The mix proportions of the control mortar is presented in Table. 1. Table 2 shows the mix proportions of the rubberised mortar. Commercially available amorphous metallic fibres are added with a content of 20, 30 and 40 kg/m^3. Used fibres come in flexible ribbon form (24 μm thick, 1.0 mm wide and 15 mm long, as presented in Fig. 2a), are stainless and have high tensile strength (⩾1.4 GPa). They are suitable in the case of thin bonded overlay and are especially convenient in the most aggressive environments. Two volumes of rubber aggregates in replacement of 20% and 30% by volume of mineral aggregates were used. Because of their lower density (1.2), rubber aggregates are strongly sensitive to segregation. In order to prevent this phenomenon a viscosity agent (Sika 300) was used and a super-plasticiser was adjusted to ensure the workability of the mixture. Fig. 2b shows that the precautions taken make it possible to avoid the segregation of rubber aggregates which are uniformly distributed in the composite. A nomenclature designating the compositions and allowing them to be easily referenced was adopted. The numbers before the letters R (Rubber) and F (Fibres) represent the volume fraction of rubber aggregates replacing mineral ones and fibre content, respectively. For example, 20R30F means the mortar incorporating 20% of rubber aggregates and reinforced by 30 kg/m^3 of fibres.

Table 1
Control mix proportions 0R0F (values in kg/m^3).

Cement	Sand	Water	Stabiliser	Plasticiser
500	1600	235	0.9	3.25

Table 2
SFRRM proportions (values in kg/m^3).

Mix	Cement	Sand	Water	Rubber	Fibre	Stabiliser	Plasticiser
0R20F	500	1600	235	0	20	0.9	3.25
0R30F	500	1600	235	0	30	0.9	3.25
0R40F	500	1600	235	0	40	0.9	3.25
20R0F	500	1280	235	140	0	0.9	3.25
20R20F	500	1280	235	140	20	0.9	3.25
20R30F	500	1280	235	140	30	0.9	3.25
20R40F	500	1280	235	140	40	0.9	3.25
30R0F	500	1120	235	215	0	0.9	3.25
30R20F	500	1120	235	215	20	0.9	3.25
30R30F	500	1120	235	215	30	0.9	3.25
30R40F	500	1120	235	215	40	0.9	3.25

2.2. Tests

The 28-day compressive strength and modulus of elasticity were determined according to European standard NF EN 12390-3 and RILEM CPC8 recommendations, respectively [13]. Cylindrical specimens (118 mm in diameter and 236 mm in height) that had been continuously cured at 20 °C and 100% R.H were then tested on a 1500 kN servo hydraulic testing machine. The faces of the specimens were ground to impose high parallelism. The tests were carried out by controlled loading at the rate of 0.5 MPa/s. For the modulus of elasticity a special extensometer, the J2P illustrated in Fig. 3 was used. It is provided with three LVDT(s) displacement sensors for longitudinal strain. The Young's modulus was calculated according to the normal stress-longitudinal strain curve according to Rilem recommendations.

Tensile tests aim to obtain the tensile strength and the post peak residual strength versus crack opening (σ–w relationship). They were conducted on 100 × 100 × 150 mm notched prisms as shown in Fig. 4. Six specimens were tested for each mix. The prisms were glued on to AU4G shoulders which were fixed to the frame of the press so that any rotation was prevented. The tests were loop controlled by reference with notch opening measured by two LVDT(s) fitted as shown in Fig. 4. The notch opening was increased at the rate of 5 μm/ min until it reached 0.1 mm. Afterwards the rate was increased to 100 μm/ min according to the Rilem recommendations [14].