Influence of Electric Arc Furnace Slags on the mechanical properties of concrete

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Introduction

Due to the outbreak of the Sars-Cov-2 pandemic, the steel production in Italy decreased by around 12%, from 23.2 million tonnes in 2019 to 20.4 million tonnes in 2020. Despite this, Italy is still the European leader in steel production by electric arc furnace: about 85% of the total 20.4 million tonnes in 2020 (17.28 million tonnes) were produced by electric cycle technology (World Steel Association, 2021). This steel production also gives rise to Electric Arc Furnace slags (EAF), in quantity estimated at around 3 million tonnes, considering 150–180 kg of EAF slag per tonne of steel produced (Piemonti *et al*, 2021). Unfortunately, today a large amount of these slags is still disposed in landfills (45–50%), thus failing to exploit their full potentials for possible future reuses. The characteristics of EAF slags make them, after appropriate treatments and processing, suitable for different reuses, especially as aggregates for road construction (Sorlini *et al*, 2012; Ferreira *et al*, 2016), partial replacement of cement (Parron-Rubio *et al*, 2018) and natural aggregates for the concrete production (Pellegrino *et al*, 2013; Monosi *et al*, 2016; Diotti *et al*, 2021). The aim of the present work is therefore to study and analyse the behaviour of the concrete with the addition of different percentages of EAF slags.

Materials and methods

Four concrete mixtures with the addition of different percentages of 24h pre-saturated EAF slags (0, 10, 25 and 50%) were studied in this work. The cement used was a Portland cement CEM 42.5 R II/A-LL with limestone. The aggregates were divided in fine sand (0–2 mm), medium sand (0–5 mm) and gravel (6–20 mm). The EAF slags used came from a steelmaking plant located in northern Italy: slag size, specific weight and water absorption values are 0–16 mm, 3600 kg/m^3 and almost 2%, respectively. The water/cement (w/c) ratio was set at 0.5 for all four mixtures considered and a minimum amount of superplasticizer was used to control the workability. Each mixture was named with an abbreviation indicating the percentage of slag–natural aggregate substitution: NAT ("Natural" mix, standard concrete, without the addition of EAF slags), 10%, 25% and 50% (mix with 10%, 25% and 50% substitution of natural aggregate with slag, respectively). Both the rheological properties in the fresh state (workability, air content and density) and the characteristics in the hardened state (compressive strength at 3, 7, 14, 28 and 60 days of curing, elastic modulus at 28 days of curing and shrinkage at 2, 3, 5, 7, 14, 28, 60, 75 and 90 days of curing) were evaluated. Throughout the curing period, 150x150 mm cubes (compressive strength) and 150x300 mm cylinders (elastic modulus) were placed in a tank filled with water and removed 24h before each deadline. The drying shrinkage prismatic specimens were placed in a climatic chamber at (20±2)°C of temperature and (50±5)% of relative humidity.

Results and discussion

The workability was assessed by means of the Abram cone slump test, according to UNI EN 12350-2 legislation. All the four mixes showed a slump between 17 and 19 mm, thus being within the limits imposed by the standard for consistency class S4 (UNI EN 12350-2). By using a porosimeter, the air content of the four mixes was measured. The mixtures considered showed a very similar air content: 2.4% for the NAT mix and about 2.5% for the other three mixes with the addition of EAF slags (thanks to the pre-saturation of the slags). The density values in the fresh state were 2440, 2510, 2610 and 2830 kg/m^3 for the NAT, 10%, 25% and 50% mixes, respectively. The density increased with the increase of slag–natural aggregate percentage substitution, due to the higher specific weight of the slags compared to that of natural aggregates (+30% approx.). The compressive strength R_{cm} increased with the increase of slag–natural aggregate percentage substitution (Fig. 1), except for the 25% mix, that showed anomalous results at low curing time. The elastic modulus E increased as the percentage of slag–natural aggregate substitution increased. Table 1 shows the values of the elastic modulus of each mix, the coefficient of variation (in brackets) and the difference with respect to the NAT mix (in percentage). Finally, considering the shrinkage, the trend was very similar among the different mixtures, with a slight increase as the percentage of slag–natural aggregate substitution percentage increases.

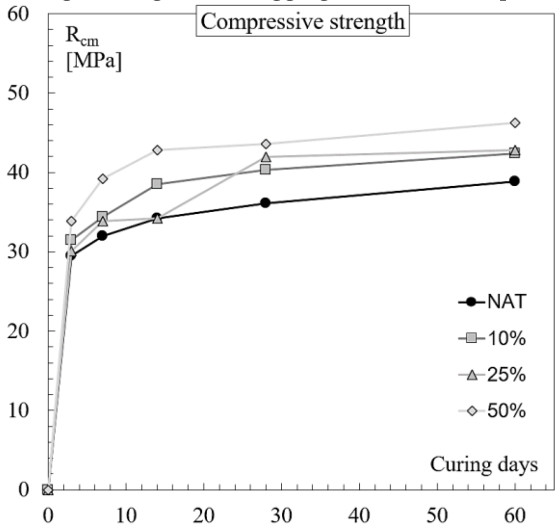

Fig 1. Compressive strength development.

Table 1. Elastic modulus *E* of each mix, coefficient of variation (in brackets) and difference (in percentage) to the NAT mix.

Mix	*E* (GPa)	Diff. (%)
NAT	33.01 *(0.02)*	-
10%	34.01 *(0.02)*	+3%
25%	36.38 *(0.06)*	+10%
50%	41.14 *(0.10)*	+25%

Conclusions

The results showed the suitability of EAF slags as a partial replacement of natural aggregates for concrete production, up to the 50% replacement tested in this paper. A correct design of concrete mix, appropriate slag pre-treatments and a control of the rheological properties during concrete mixing are necessary to get concrete with similar or even better performance characteristics than the standard one, with the possibility of further future studies involving mainly aspects related to the durability and the environmental impacts of the material.

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