Quarry limestone dust as fine aggregate for concrete

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Abstract. In quarrying activities, rock is extracted and transformed into aggregate of various sizes for civil engineering applications. In this process waste fine aggregates (dust waste) are generated. The disposal of this type of waste is a further cost in the extraction process, but also a possible cause of environmental pollution (e.g. leaching into water reserves, atmospheric pollution as a result of small particles causing respiratory diseases or deposited on plants disrupting photosynthesis, affecting aquatic habitats, etc.). A strategy for the effective recycling of quarry dust does not only reduce waste generation and disposal, but also addresses protection of the environment. The Italian quarrying industry covers a relevant portion of global mineral extraction resulting in a significant production of fine waste. In some cases quarries are located close to ecological sensitive and protected areas and to the coast with higher risks for biodiversity (an example is the limestone extraction industry in Trapani, Sicily). In this context, the paper reviews the strategies proposed in the use of limestone fine waste, especially for concrete, and discusses an experimental program intended to assess the mechanical properties of concrete made with the fine limestone waste produced in the area of Trapani, as a partial substitute of fine aggregate (sand).

Keywords: Quarry limestone dust, limestone waste, fine aggregate, mechanical properties

1. Introduction

There has been an increase in awareness on the need for sustainable development to guarantee a rational use of the earth resources. Quarrying activities, as a result of large demands for mineral resources including aggregate for civil engineering works, have a significant impact on the environment and wellbeing in society.

Quarrying of stone intended for construction related and civil engineering applications include also the extract of stone for ornamental products, stone to be processed as dimensioned stone or as paving or cladding slabs resulting in significant amount of waste rock including coarse and fine material. The latter is generally the result of the cutting machines in quarries.

In the case of stone extracted for ornamental stone products the marble quarries are known to generate a particularly large quantity of waste. 18% of global marble extraction is concentrated in Italy. The main sites for the extraction of marble are located in Tuscany (in the province of Massa Carrara) and in Sicily (in the province of Trapani, in Custonaci). The marble in Custonaci is effectively a limestone and not a metamorphic stone as marble is by the geological point of view. Nevertheless, it is worked as it was a marble and for this reason it is improperly called marble being in all a marble by the physic point of view.

Approximately 200 quarries are located around Massa Carrara while about 70 quarries are located in Custonaci. Only 20% of the extracted material is used commercially, while the remaining 80% is waste generated through the activities. It is estimated that about 50% is constituted by rocks of various size while 30% is dust. 6 million tons/year are extracted in Italy of which 4.8 million tons consist of quarry waste including 1.8 million tons of waste dust.

As a consequence of the intense quarrying activity over the years, the marble basins of Custonaci (figures 1-3) and Massa Carrara are characterized by enormous volumes of accumulated discarded deposits resulting from the quarrying activity (in some cases these can reach dozens of hectares). Generally, waste is pushed towards the slopes close to the quarry areas, threatening the integrity of landscape and of the environment in particular with regards to ground water and surface water contamination, or even because of atmospheric contamination due to dust dispersion [1]. Furthermore, quarry waste represents one of the principal sources of hydro-geological instability, leading to rock-falls and debris flow.

a) b)

Figure 1. a) View of Sicily indicating the area of Custonaci (in the red circle); b) the area of Custonaci indicating (in white) the distribution of quarries.

Figure 2. Waste near a quarry in Custonaci

Figure 3. Quarry dust in Custonaci

In the past, different quarry waste deposits have provoked landslides. During the initial deposition of the quarry waste the material accumulates in heaps based on the angle of friction. The continuous storage and increment of the volume of waste results in alterations to the slope boundaries. Therefore, sudden landslides can be activated, even more frequently during periods of intense rainfall.

Over the years the accumulation of waste has become a significant problem due to the large volumes of waste generated. As a result different strategies for disposal of the material are investigated. In most cases the main focus is, first, how to possibly reduce the volume of waste generated, and then how to transform the waste into a resource. With reference to the marble industry, for a long time the economic interests have been a priority. The profits deriving from the 20% marketable extracted materials have distracted the attention of the industry from the waste generation problem. However there is a growing interest on the waste generated and how the large volumes of waste generated can be transformed into an opportunity through recycling.

Effectively, such a huge quantity of quarry waste may represent a resource of good quality. Different studies have addressed the quarry marble waste (at least the part that can be processed as coarse aggregate) suitable as inert materials for civil engineering applications including road and railway construction works and in the production of concrete and concrete products. Recycling of the material on one hand can solve the problem of disposal and, on the other hand, is considered to be favourable from an environmental point of view because it leads to a reduction in the demand of new quarries for the production of coarse aggregate for concrete or for civil engineering applications. Nevertheless, referring to marble quarries, a non-negligible part of the waste (30% of the material extracted) consists of dust waste or a dust-water mix (the water is used during the cutting and trimming of the blocks using the diamond wire cutting machines, to allow for cooling). The recycling of the quarry dust waste is more challenging.

Regulations impose the transportation to landfill of the dust or the water-dust mix, but the high cost involved, suggest recycling of the material for uses in different fields.

Many researchers have tried to exploit quarry dust for the production of concrete. The quarry dust has been used as partial or full substitute of the sand. Rai et al [2] carried out an experimental investigation based on the substitution of the sand with quarry dust for the production of self-compacting concrete. Different quantities of sand are substituted up to 100% and the strength of the concrete was assessed. Prakash et al [3] assessed the use of dust for normal concrete, reporting that a 40% replacement of fine aggregate by quarry dust resulted in the highest compressive strength. In the study reported by Bahoria et al [4] sand was replaced with quarry dust in combination with waste plastic. A similar investigation was carried out by Aishwaryalakshmi et al [5] where up to a 30% substitution of fine aggregate was assessed. Other studies have addressed the replacement of sand with quarry dust for the production of concrete (e. g. Jagadeesh et al [6] and Liebermann et al [7]). In some cases, the mechanical properties of non-conventional concrete was investigated, as reported by Lim at al [8] where the use of quarry waste for lightweight foam concrete was considered. A literature review of the strategies used in the replacement of aggregate for concrete with waste is presented by Bahoria et al [9] focusing mainly on the strength characteristics. However, some studies on the stress strain characteristics of concrete made using quarry dust waste are reported in literature (Kankam et al [10]). An interesting strategy refers to the use of quarry dust for the production of coarse aggregate through a cold bonding procedure as reported by Thomas et al [11-12].

With regards marble quarries, different strategies have been employed for the use of coarse aggregate in concrete as reported by André et al [13].

The potential recycling of waste marble dust in Sicily has not been explored yet. The objective of the research is to explore the potential use of waste marble dust derived from the Sicilian marble industry, through an experimental investigation.

The marble in Custonaci (that, as above mentioned, is improperly said marble because it is a limestone worked as a marble) has an age varying from the Cretaceous to the Eocene. It is a sedimentary rock constituted mainly by calcite (98%) and (2%) dolomite, apatite, illite, goethite and quartz. It originated in a marine environment, after some processes of alteration, erosion, transport and deposition of debris of pre-existing rocks and/or animal or plant remains. The marbles of Custonaci can be fossiliferous or non fossiliferous, stratified, sometimes coloured with different pigmentation. The physical-mechanical characteristics are as follows: unit volume weight 23-26 kN/m^3, thermal expansion coefficient 0.0047-0.0043 mm/m°C, compressive strength 160-200 MPa, compressive strength after freezing 155-195 MPa, tensile strength 13-17 MPa.

2. Experimental program

In this study the fine aggregate of a reference control mix has been progressively replaced with a single type of quarry dust sourced from Custonaci, at two different levels of substitution. The experimental study reported forms part of a more extensive research. The paper presents the first results, which are discussed and compared with data available in literature.

2.1 Materials

The reference concrete was produced using portland limestone cement Type 32.5 as the hydraulic binding agent, together with quarry rock of 2 mm nominal maximum size used as fine aggregate, and 20 mm crushed rock coarse aggregate. The particle size distribution of the fine aggregate is presented in figure 4.

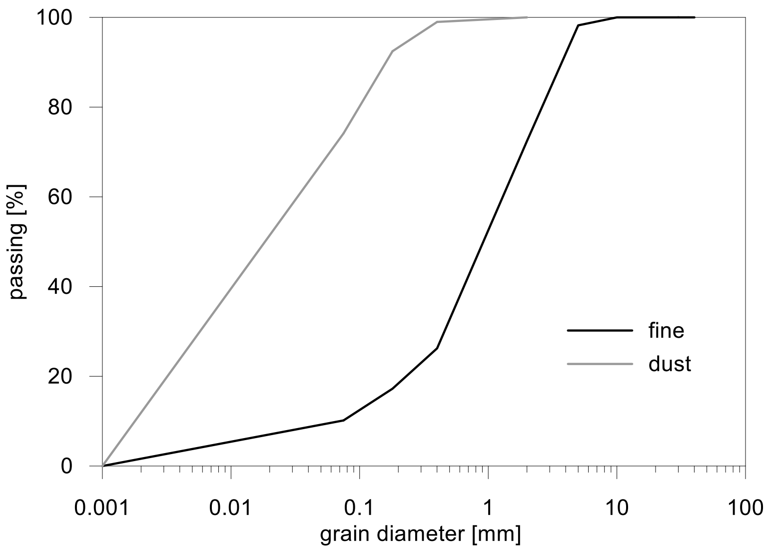

Figure 4. Fine aggregate and quarry dust: granulometric curves

The sand (having a specific weight of 2860 kg/m^3) was replaced by a marble quarry dust with granulometric characteristics as presented in figure 4.

2.2 Mix proportion and preparation of test specimens
The reference concrete was prepared using a mix typical for obtaining a 28 days characteristic strength of 30 MPa. The mix consisted of 315 kg of cement, 798 kg of coarse aggregate, 735 kg of sand per m^3 of concrete, with a water/cement ratio of 0.5.

The concrete mixes were prepared in the materials laboratory of the University of Palermo (each mix volume was approximately 1/21 of a m^3 in agreement to the characteristics of the mixer. Therefore, the reference mix was composed of 15 kg of cement, 38 kg of course aggregate, 35 kg of sand and a water/cement ratio of 0.5. In total, 11 cubic test samples (15 cm cubic specimen) were produced for each mix. Six mixes were prepared: two reference mixes and further four mixes with different levels of replacement of fine aggregate. The four mixes consisted of the same quantities of cement, water and coarse aggregate as for the reference mixes. However the fine aggregate portion was composed of 31 kg of sand and 4 kg of quarry dust for two of the four cases, and 27 kg of sand and 8 kg of quarry dust for the remaining two mixes. The concrete mixes had a similar slump class in the range 30-60 mm, but which was reduced with the increase in the quarry dust content in the concrete. The concrete mix proportions are presented in table 1 with reference to a cubic meter of fresh concrete. The laboratory mix proportions are presented in table 2.

Table 1. Mix proportions per cubic meter

Id. mix	Portland cement 32.5 kg/m^3	Coarse aggregate kg/m^3 (m^3)	Sand kg/m^3 (m^3)	Dust kg/m^3	Water l/m^3
1-2	315	798 (0.7)	735 (0.5)	-	157
3-4	315	798 (0.7)	651 (0.44)	84	157
5-6	315	798 (0.7)	567 (0.39)	168	157

Table 2. Mix proportions referred to 1/21 of a cubic meter

Id. Mix	Portland cement 32.5 kg per 1/21 m^3	Coarse aggregate kg per 1/21 m^3	Sand kg per 1/21m^3	Dust kg per 1/21 m^3	Water l per 1/21 m^3
1-2	15	38	35	-	7.5
3-4	15	38	31	4	7.5
5-6	15	38	27	8	7.5

The percentage of sand replacement in the concrete mixes was 13 % (mixes 3 and 4) and 26% (mixes 5 and 6) respectively. The cement and aggregates were first mixed together in a mixer. Water was then added and mixing was continued until a uniform and homogenous matrix was obtained. The fresh concrete was cast in 150 × 150 × 150 mm moulds and compacted with a concrete vibrator. The specimens were de-moulded after 24 hours and cured by immersion in water at 21 °C. The cubes from the mixes 1-3-5 were used to obtain the compressive strength of the concrete after three, seven and fourteen days. The cubes from the mixes 2-4-6 were used for tests carried out at 28 and 60 days.

2.3 Discussion
The results of the compressive strength tests on each cube at 3, 7, 14, 28, 60 days are presented in figure 5. It is immediately clear that the replacement of 13% of the sand produces an increase of the strength while the replacement of the 26% of the sand produce a decrease of strength variable with the

days of curing. The strength of the mix characterized by a sand replacement of 26% is recovered at 60 days. Further, a greater dispersion of the compressive strength results was observed for the mixes with no replacement and replacement of 13 % of the sand.

Figure 6 presents the average results of the compressive strength tests showing the effect of sand replacement with Custonaci quarry dust. In spite of the replacement of 26% of sand resulting in a decrease of the strength with reference to the control mix, the reduction in strength is less at 14 days than at 7 days and negligible at 60 days. This is clearer in figure 7 where the increment factors of each mix at 3, 7 and 14, 28 and 60 days are normalized with respect to the strength at 3 days. This factor is obtained as a ratio between the strength obtained at each reference time and the strength obtained at 3 days. For each mix the starting point at 3 days is therefore 1 and greater values are obtained depending on the strengths reached. From figure 7 it can be observed that the reference mix and the mix characterized by a sand replacement of 13 % have a similar strength increment, indicating a 14-day strength approximately 1.7 times greater than the 3 day strength. On the other hand the mix characterized by a sand replacement of 26% has a higher gain in strength between 7 and 14 days, with a 14-day strength approximately 2 times greater than the 3 day strength. A similar consideration can be done at 28 and 60 days.

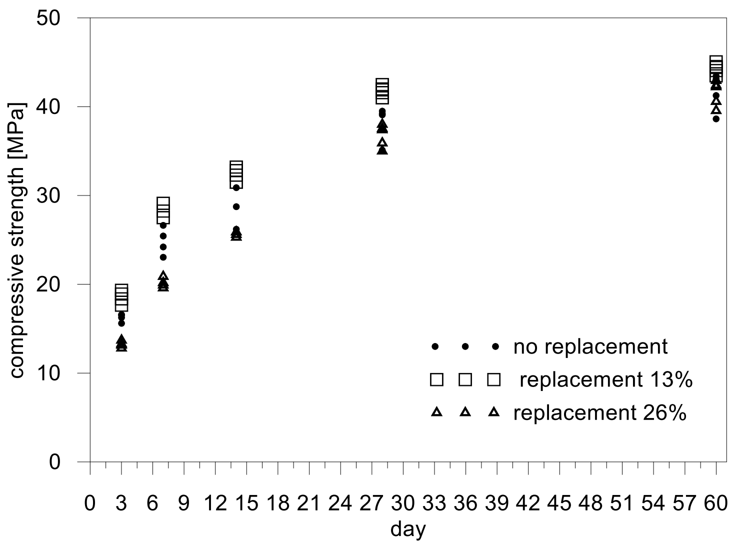

Figure 5. Strengths of each cube at 3,7, 14, 28, 60 days

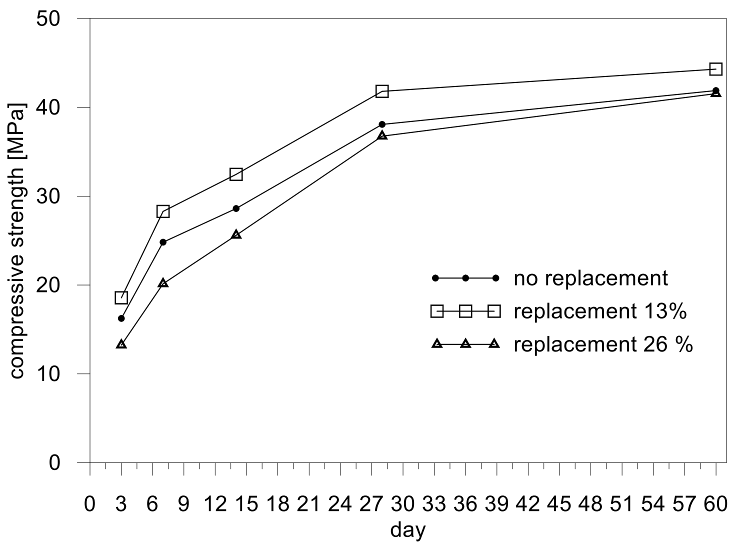

Figure 6. Average strengths at 3,7, 14, 28, 60 days

It appears that the dust slows the gain in strength of the concrete, at least in the first days after casting but there is an indication of a recovery in the gain in strength with time.. In figure 8 this concept is illustrated through the percentage of variation of strength at 3, 7, 14, 28 and 60 days with respect to the reference mix. It is shown that the mix with 13% sand replacement maintains a constant strength greater than 15% with respect to the reference mix during the first 28 days of curing. The mix characterized by a 26 % replacement of sand indicates a reduction in the gap from -18% to about -10 % (at the 14th day) with respect to the reference mix. This gap is further reduced at 60 days (2%).

In each case the above-mentioned figures indicate that replacement of sand with dust obtained from the quarries of Custonaci has potential for use in concrete. From 14 to 60 days curing, the increment in strength observed for the mix with 26% sand replacement results sufficient to obtain a strength very close to that of the control mix.

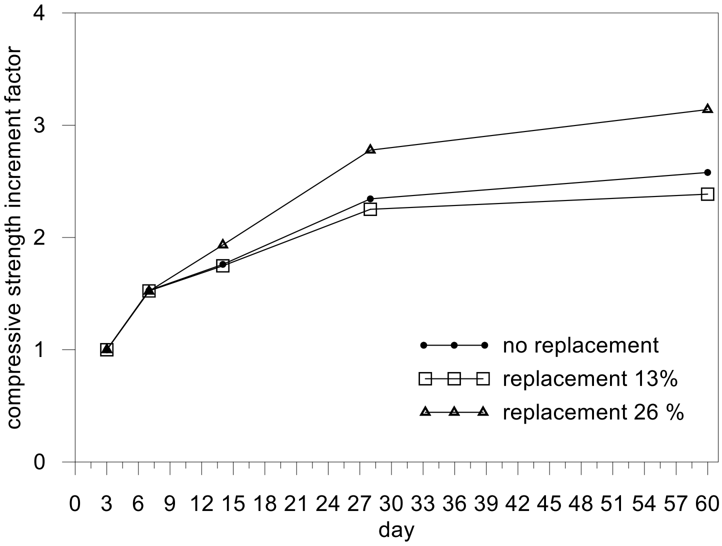

Figure 7. Strength increment factors

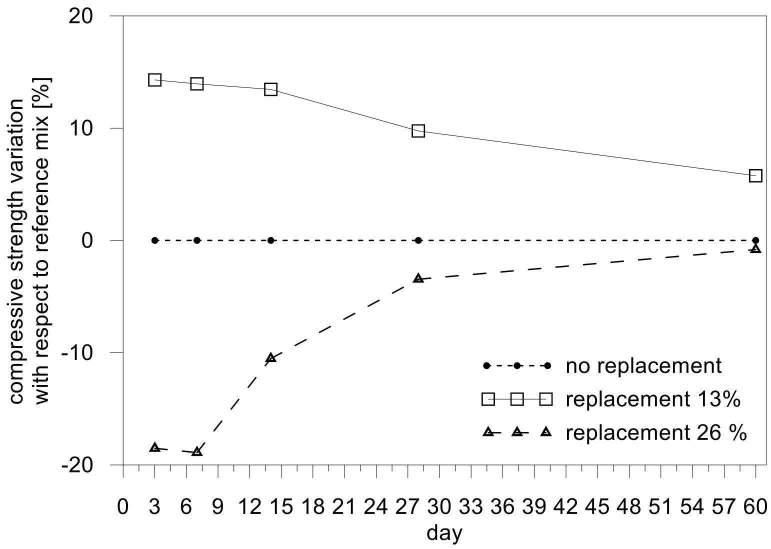

Figure 8. Percentage of strength increment with respect to the reference mix

3. Comparison with some experiences reported in literature

With regards to the replacement of fine aggregate with quarry dust in the production of concrete, the results reported in literature for mechanical properties of concrete, tend to vary from one study to another. The reason is that the final characteristics depend on the constituent material properties including the properties of the waste materials used and also on the mix design. Nevertheless, various studies reported in literature confirm the potential use of waste quarry dust in concrete as a partial replacement of the fine aggregate (sand) resulting in a concrete with mechanical characteristics that are acceptable for structural concrete.

Prakash et al [3] report on the use of the quarry dust of the Paritala region in India as a substitute of the fine aggregate for concrete. Different concrete grades are studied. The results reported for M30 and M20 concrete with a 53-grade cement are of particular interest. For the first case the results are included in figure 9 while for the second case the results are included in figures 10-11.

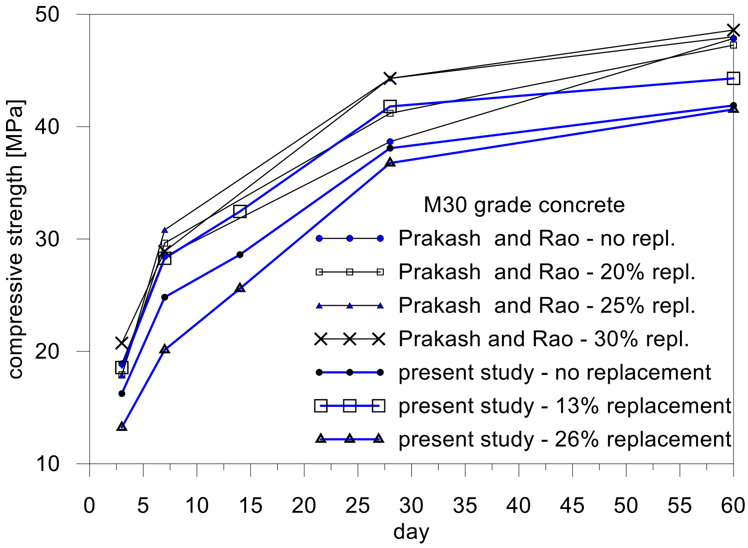

Figure 9. M30 concrete – Compressive Strength of the concrete mixes proposed by Prakash et al.

Figure 9 shows the results for concrete produced with sand replacement up to 30%. The results proposed are in contrast with the results obtained in the present study because the results reported by Prakash et al indicate a continuous increase in strength for increasing levels of replacement with respect to the reference mix. For sake of clarity the mean strength of the mixes analysed in the present study are inserted in figure 9, showing also that the strengths obtained in the present study during the curing are lower than those of the mixes reported by Prakash et al. This difference is possible also due to the different mix design and different cement used for the mixes. Prakash et al use a 53-grade cement while a 32.5 grade cement is used in the present study.

Prakash et al reported that larger amounts of dust (more than 50% replacement) cause a reduction of strength of the concrete as show in figures 10-11, which refer to a M20 grade concrete.

This fact is clearer in figure 11 where the strengths are directly correlated to the percentage of sand replacement and where a first reduction in strength is reported at 10% substitution of sand followed by an increase in strength.

Kankam et al in [10] present the results of a research carried out in Ghana where two levels of replacement of fine aggregate with quarry dust were investigated. In particular 25% and 100% replacement levels were considered showing the advantages of the substitution of fine aggregates with quarry dust in both cases.

Three target concrete strengths were investigated in the study. The compressive strengths for a M30 grade concrete at 28 days are presented in table 3.

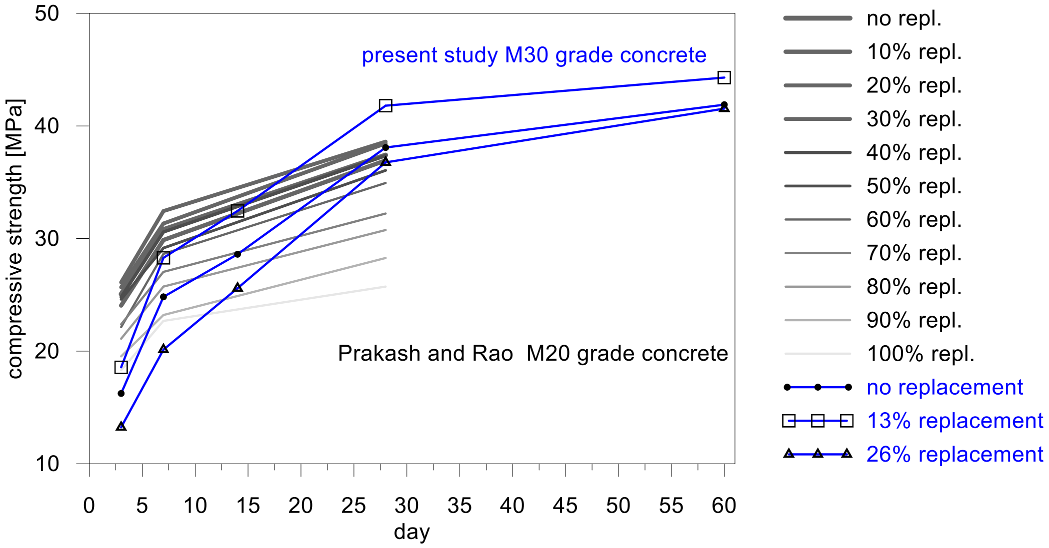

Figure 10. M20 concrete - Strengths of the mixes proposed by Prakash et al

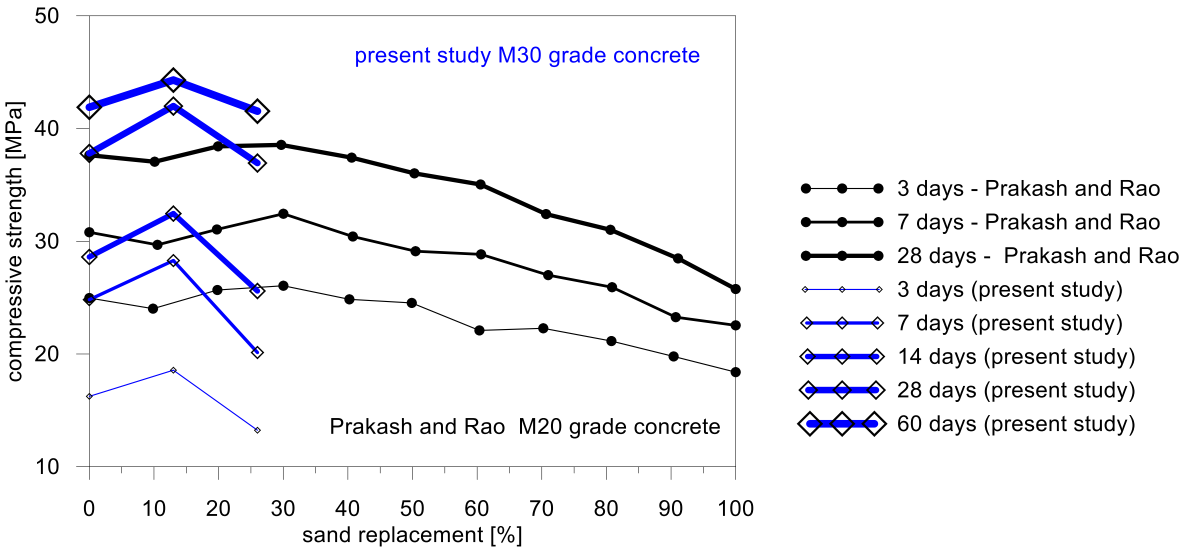

Figure 11. M20 concrete - Strengths of the mixes in Prakash et al, with varying percentage replacement

Table 3. Characteristics of some concrete mixes Kankam et al [10]

Concrete grade [MPa]	Fine aggregate replacement [%]	Cement in the mix [kg/m^3]	w/c	Fineness of sand	Fineness of quarry dust	Strength at 28 days [MPa]
30	0	397	0.56	2.66	3.54	30.50
30	25	416	0.56	2.66	3.54	31.20
30	100	429	0.56	2.66	3.54	30.17

In the study conducted by Kankam et al [10] it appears that the quarry dust used has a fineness modulus greater than that for the sand. It means that the particles constituting the waste used are coarser than those used in the present study. Therefore, the low reduction of strength exhibited with increase in quarry waste is not due to the introduction of a fine aggregate having the characteristics of a filler but for the introduction of a fine aggregate with grains greater than that of the sand. This demonstrates the importance and relevance of the characterisation of the waste quarry dust, which is transformed into a product, as substitute for industrial grade sand. Furthermore the quantity of cement used per cubic meter of concrete, (the cement grade is not given), is much higher than that employed in the present study and increases with increasing quarry waste in the mix. This strategy for compensating for the negative effect of inclusion of waste through the additional of cement gives better results, but also implies additional costs in production.

4. Conclusions

The paper presents preliminary results of an investigation intended to explore the potential of waste quarry marble dust from Custonaci (Sicily) for the production of concrete. The study has the objective of exploring practical options for the recycling of the large quantities of waste therefore addressing environmental concerns. The study refers to mechanical properties of the material and includes also a comparison with some experiences reported in literature.

The results indicate that the marble dust investigated in this research, having the characteristic of a filler, can be effectively used for the production of concrete, with improvements in mechanical characteristics if used in low quantities. Lower mechanical properties were reported when the waste is used in larger quantities. In the latter case the loss in performance is however such that it can be compensated with an increase in the cement content of the mix.

Similar experiences are reported in literature. In those cases negligible reduction of strength has been encountered even if a 100% replacement of fine aggregates has been done. However different results are also due to the different variables considered including varying materials and mix designs, the characteristics of the waste dust used and the cement type and cement content.

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