Iron ore dust as a natural pigment in concrete with RCA for artwork application

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Synopsis: The innovative idea of utilizing iron ore dust (IODust), characterized by a red hue typical for Narvik, came up during designing artwork for The Arctic University of Norway campus Narvik. The use of waste from iron ore production as a natural pigment was completed by partial replacement of natural aggregates (NA) by recycled concrete aggregates (RCA) to achieve a higher level of material circularity and demonstrate the potential of secondary raw material integration in concrete. Concrete in class C35/45 with 72 kg [158.73 lbs] of IODust, 5% replacement of fine NA and 12% of coarse NA was designed for artwork. Monitored properties were workability, air content, compressive strength and modulus of elasticity. Furthermore, chloride migration coefficient was measured on mixes with and without IODust as an indicator of durability. The use of IODust might not serve only as natural pigment but also increase concrete durability, which is a subject of further research.

Keywords: Coloured concrete; IODust; iron ore dust; natural pigment; RCA; recycled concrete aggregates

INTRODUCTION

The artwork at UiT Narvik, Norway, was designed by Lene Baadsvig Ørmen and was recently finished. The artwork consists of three parts: a large concrete sculpture situated in the park, a sound piece composed by Peder Simonsen and six small wall sculptures cast in bronze. The central element is the large concrete sculpture positioned on a coloured concrete pedestal.

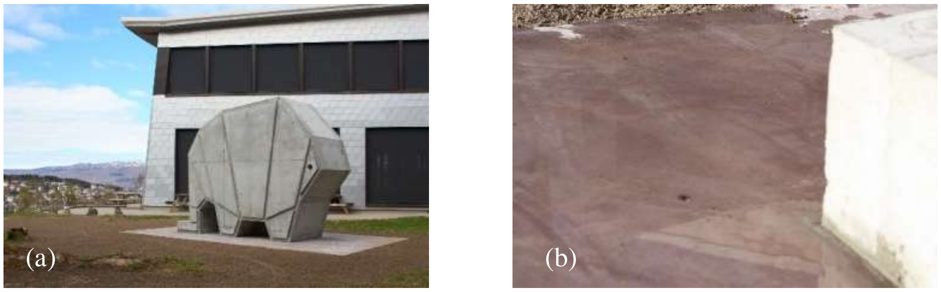

Fig. 1–(a) artwork; (b) pedestal from coloured concrete.

Artist wanted to include materials relating to Narvik's history and the artwork's site in a conceptually subtle yet poetical and expressive manner. Upon arrival in Narvik, the artist noticed how there was purple-like iron ore dust gathering on surfaces everywhere. Therefore, the artist decided to include this local phenomenon in the sculpture, and by doing so, iron ore dust was used as a natural pigment for colouring concrete used for a pedestal (6.0×4.5×0.2 m [236.22×177.17×7.87 in.]).

Secondary raw materials are materials, that are considered waste and in a given industry does not have further use. Integration of industrial waste and mining tailings into the building industry increases, and adaptation of good practices such as recycling and reuse are highly discussed topics at the moment. Improvement of material circularity is one of the main approaches worldwide, and therefore Norwegian research Council funded in 2019 project Circulus focused on reuse, recycling and recovery of construction and demolition waste (CDW). CDW in Norway is composed predominantly of concrete and wood, as those are the most common building materials there. Concrete debris can be further processed by crushing and sieving into RCA. The quality of RCA is based on sorting level at a demolition site, type of processing technology, and parent concrete properties [1]. The level of sorting can influence mainly the amount of impurities in RCA, but the type of processing technology and properties of parent concrete have an impact on the quality and characteristics of RCA itself. Currently, RCA is mostly used as a filling material for earthwork and barely as a replacement of natural aggregates in new concrete. Integration of RCA in concrete is allowed by a standard, but it is not widely adopted in the industry, and therefore we decided to use this opportunity for a practical showcase of concrete prepared with two types of secondary raw materials. The first is IODust originate from iron ore processing and the second are RCAs processed from concrete waste generated in concrete plants located in Northern Norway.

EXPERIMENTAL INVESTIGATION

The iron ore mines (predominantly magnetite) in Kiruna are operated by LKAB, a government-owned Swedish mining company. LKAB has been in operation since 1890, and its main products are two types of pellets, Blast Furnace Pellets and Direct Reduction Pellets, which represent about 80% of total production. Pellets are produced from iron ore concentrate with the addition of clay mineral and bentonite, which serves as a binder during the pelletizing process. Formed pellets with a diameter of 10 mm are dried and pre-heated by the exothermic reaction of magnetite, which oxidizes into hematite. In order to get the strength of pellets, sintering at approximately 1250 °C [2282 °F] takes place before cooling and transportation of the final product. Pellets made from magnetite have an iron content of around 67%, making them a high-quality product [2].

The iron ore dust is created during the re-loading of pellets from train carriages into silos and subsequently to bulk carriers in the Narvik harbour. The IODust created during the material manipulation is filtered away and further sold as SCM for a fraction of the pellet´s price. Its chemical composition is predominantly iron, see Table 1. The element composition of IODust was analyzed by Hitachi handheld XRF set on the mode MiningLE-FP and match results obtained by Eklund and Dahlstedt [3].

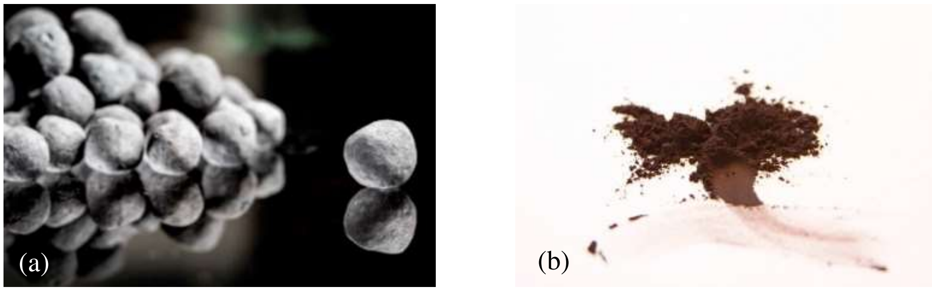

Fig. 2–(a) iron ore pellets [4]; (b) iron ore dust.

Table 1–Iron ore dust chemical compound composition [3] and element concentration.

Chemical compound	Pellet no 1 [%]	Pellet no 2 [%]	Element	Concentration [%]	Accuracy [+/-]
Fe tot	66.30	66.90	Fe	68.87	0.047
FeO	0.40	0.40	Mg	0.28	0.148
MgO	1.55	0.50	Si	1.34	0.009
SiO_2	2.15	2.35	Ca	0.45	0.001
b2 (CaO/SiO_2)	0.22	0.23	–	–	–

Specimens

Concrete prepared for artwork contains 5% of fine RCA and 12% of coarse RCA; the total replacement was 6.5%, demonstrating the possibility of RCA use in concrete for non-structural purposes. The amount of IODust was first tested in 2 different doses (15% and 20% of cement dose) while the amount of cement was constant, and IODust was considered as inert addition. Properties of fresh concrete, evaluation of colour hue and compressive strength of hardened concrete were tested. Artist, Lene Baadsvig Ørmen, decided for 20% of IODust of cement dose as the colour matched her expectations the most. The mix design was slightly adjusted for concrete truck production in the local concrete plant. The RCAs, white cement (strength class 52.5 MPa [7614.48 psi]) and IODust were added directly to the concrete truck, while natural aggregates, water and superplasticizer were dosed through the mixing station. The total amount of prepared concrete was readjusted from 4,4 m^3 [5,75 yd^3] to 5,4 m^3 [7,06 yd^3], and 1 m^3 [1.31 yd^3] of regular concrete with grey cement (strength class 42,5 MPa [6164.10 psi]) was added. Testing of fresh concrete took place at the construction site approximately 45 minutes after the initiation of mixing, before the pouring into the framework with prepared reinforcement. Concrete was finished by vibration and covered by a plastic sheet to prevent rapid water evaporation and ensure good curing conditions. Prepared coloured concrete with IODust and partial replacement of natural aggregates by RCA matched all fresh state requirements - air content below 2% and workability class S5 (slump $\geq$ 220 mm [8.66 in.]). Properties of hardened concrete were compared with results obtained during the lab stage, where two various amounts of IODust were tested. Compressive strength was the main tested property completed with elastic modulus and chloride migration analysis according to NT Build 443 [5] performed on pedestal mix.

EXPERIMENTAL RESULTS AND DISCUSSION

During the laboratory stage, 3 mixes with IODust 0%, 15%, and 20% of cement dose (equal to 0 kg, 54 kg [119.05 lbs] and 72 kg [158.73 lbs] of IODust) per 1 m^3 [1.31 yd^3] of concrete were prepared. The final concrete mix was adjusted for industrial mixing and the requested quantity.

Fresh concrete properties

Workability ranged from 220 to 250 mm [8.66 to 9.84 in.], see Table 2. Mix M-IODust-15% had significantly higher air content which reduced the compressive strength of hardened concrete. The reason for high air content might be a longer mixing time.

Table 2–Fresh concrete properties of tested mixes and water/powder ratio with SP dose as the determining parameters for workability.

MIX-IODust-x%	Water/powder ratio	Superplasticizer [%]	Slump mm [in.]	Flow [%]	Air content [%]	Density kg/m^3[lb/ft^3]
M1-IODust-0%	0.42	1.5	230 [9.06]	455	1.7	2415 [150.75]
M2-IODust-15%	0.41	1.2	250 [9.84]	590	8.5	2313 [144.38]
M3-IODust-20%	0.41	1.0	240 [9.44]	715	1.3	2435 [152.00]
Pedestral-IODust	0.37	1.0	220 [8.66]	440	1.9	2430 [151.69]
M1-IODust-0%	0.42	1.5	230 [9.06]	455	1.7	2415 [150.75]

Thanks to the use of white cement, the impact of IODust on the color of concrete was more visible and even created an interesting texture on the surface, see Figure 3.

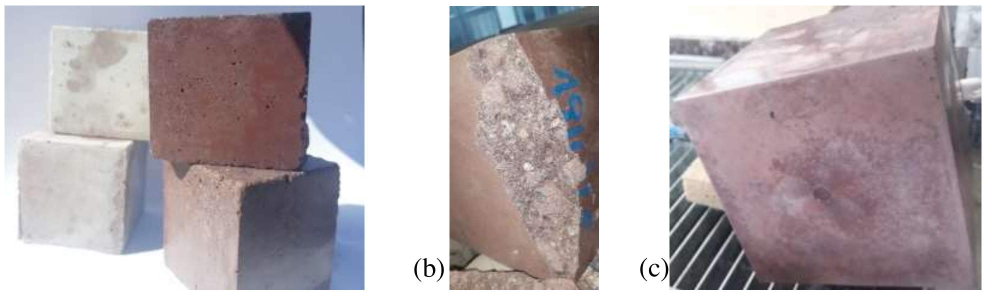
(a) (b) (c)

Fig. 3–(a) laboratory stage – 0%, 15% and 20% of IODust; (b), (c) pedestal concrete mix with 20% of IODust.

Hardened concrete properties

Hardened concrete properties fulfil the requirements of prepared concrete C35/45. The compressive strength of all mixes was significantly higher by 30.2% to 97.1% than the minimum limit for C35/45 (45 N/mm^2 [6526.70 psi] cubic compressive strength) at age 28 days. The strength difference between the M3-IODust-20% mix and the Pedestal-IODust mix was 26.5% and is most probably caused by the lower strength class of grey cement (1 m^3 [1.31 yd^3] of regular concrete added to Pedestal-IODust mix).

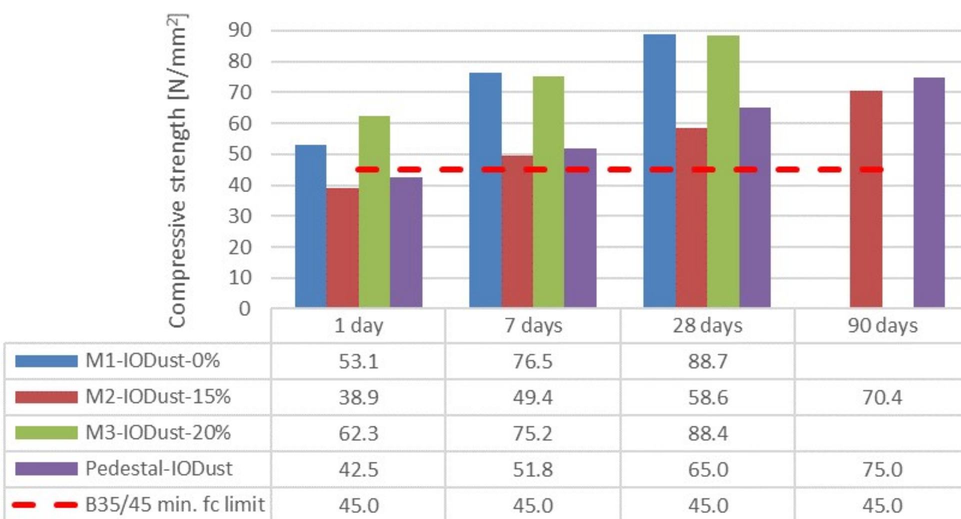

Fig. 4–Results of compressive strength testing.

Elastic modulus of Pedestal-IODust mix was 30.2 GPa [4 379 985 psi] and increased to 32.7 GPa [4 742 567 psi] after 90 days from casting. Chloride migration coefficient was comparable for mix with and without IODust, 6.46 and 6.88 m^2/s $\times 10^{-12}$ [69.53 to 74.06 ft^2/s $\times 10^{-12}$] and both mixes fitted in a high class of resistance to chloride penetration. The presence of IODust in the Pedestal-IODust mix could have an impact on test results as the accelerated chloride penetration test is based on electric current transmission, and a higher voltage was applied.

CONCLUSIONS

In this study, IODust served as a natural pigment in coloured concrete, but that might not be the only beneficial property of IODust given to concrete. In total, 5,4 m^3 of coloured concrete was prepared. Based on the results of this experimental investigation under a specific environment, the following conclusions are drawn:

1. Fresh concrete achieved designed properties -workability class S5 (220 mm [8.66 in.]) and air content 1.9%, and hardened concrete disponed by compressive strength higher by 44,5% than minimum compressive strength requested by EN206 for concrete in strength class C35/45.
2. The casting of the pedestal for the artwork was successful, and the colour of concrete given by iron ore dust turned out natural and harmonized with the surrounding ambient.
3. IODust improved the rheology of fresh concrete, omitted segregation and contributed to excellent handling properties during the casting.
4. The iron ore dust might not serve only as natural pigment but also improve durability and shielding properties [6] which is the subject of further research.

ACKNOWLEDGMENTS

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BIOGRAPHY

Nováková Iveta, Ph.D. works as a researcher at the Department of Building, Energy and Material Technology, The Arctic University of Norway. Her current research focuses on demolition processes, circular material flow, and utilization of recycled aggregates in concrete production. Furthermore, fibre reinforced concrete, basalt fibres as a possible replacement of steel fibres, fire resistance of concrete, eco-crete with low cement content, and rheological properties of fresh cementitious materials. Corresponding author e-mail: iveta.novakova@uit.no

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Ørmen Lene Baadsvig is artist who lives and works in Oslo. She holds an MFA from the Academy of Fine Arts in Oslo, and a BFA from Bergen Academy of the Arts (Dept. of Photography). Ørmen's work is represented in private and public collections, including the National Museum, the Norwegian Parliament, and Oslo Municipality. Her solo exhibitions include Hordaland Art Center Bergen (2020); The Sculptors Association, Oslo (2019); Gallery Augusta, Helsinki, and Another Space, Copenhagen.