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Beneficial use of marine dredged materials as a fine aggregate in ready-mixed concrete: Turkey example

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HIGHLIGHTS

- Beneficial use of dredged material (DM) in ready-mixed concrete (RMC).
- Utilization of DMs as partial substitution with fine aggregate (silica sand).
- Replacement of silica sand with DM (0%, 25%, 50%, 75%, 100%).
- Effect of DM on RMC's mechanical/durability, leaching, micro-structural properties.
- DMs can be beneficially used to fabricate high quality RMC.

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ABSTRACT

This study describes the potential beneficial use of untreated and treated marine dredged material (DM) in ready-mix concrete (RMC) as a fine aggregate. DMs collected from four Turkish ports/harbours were characterized, assessed according to the National Legislation and transformed into one composite DM. Silica sand was replaced with untreated- and treated-composite-DM (COMP-U/COMP-T) at five ratios (0%, 25%, 50%, 75%, 100%), respectively. Mechanical, durability, leaching, mineralogical/micro-structural properties of DM-based-RMCs were analysed. Concretes having 50% COMP-U and 100% COMP-T met the minimum requirement for C25/30 class RMC. Marine DM can be beneficially used in RMC production; however, DM pre-treatment should be applied.

1. Introduction

In Turkey, about 3 million m^3 of marine dredged material (DM) is excavated annually as a result of routine dredging activities carried out at ports, marinas and fishery harbours, and these DMs are dumped at sea in its current situation. However, the uncontrolled discharge into the sea can lead to negative impacts with physical, chemical and/or biological risks on aquatic ecosystems [1,2]. It is obvious that dumping at sea should be considered as last alternative in DM management together with upland disposal which requires high cost, large spaces and long-term monitoring [1,3,4]. Due to the ongoing annual dredging operations, the minimization of DM quantities is not applicable as the most prioritized option [1]; thus, beneficial use alternative becomes the most appropriate one. Beneficial use is a process utilizing DM as a raw material to obtain productive material and provides environmental, economic and social advantages [1].

According to Waste Framework Directive (2008/98/EC), DM is classified as a waste with the waste codes of 17 05 05* (polluted sediments) and 17 05 06 (other sediments) [2]. Due to the exhaustion of natural resources and tendency of other countries' to provide sustainable development approach, the beneficial use of DM has accepted prevalently in different application areas such as land

Abbreviations: DM, dredged material; DİPTAR, Marine Dredging Applications and Environmental Management of Dredged Materials Project; RMC, ready-mixed concrete; ERMCO, European Ready Mixed Concrete Organization; LWA, lightweight aggregate; TÜBİTAK MAM, The Scientific and Technological Research Council of Turkey Marmara Research Centre; PCB, polychlorinated biphenyl; TS, Turkish standard; SM, standard methods; ADDDY, The Regulation on the Landfilling of Waste; AYY, The Waste Management Regulation; ICP-OES, Inductively Coupled Plasma-Optical Emission Spectroscopy; DOC, Dissolved Organic Carbon; TOC, Total Organic Carbon; BTEX, Benzene, Toluene, Ethyl benzene, Xylene; TDS, Total Dissolved Solids; LOI, loss on ignition; USCS, Unified Soil Classification System; PI, Plasticity Index; LL, Liquid Limit; PL, Plastic Limit; COMP-U, untreated-composite-DM; COMP-T, treated-composite-DM; w/c, water/cement; SE, sand equivalent; MB, methylene blue; ASR, alkali-silica reactivity; XRD, X-ray Diffractometer; XRF, X-ray Fluorescence Spectrometer; SEM, Scanning Electron Microscope; EDS, Electron Dispersive Spectroscopy.

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improvement/reclamation, beach nourishment, coastal protection, landfill daily cover/liner, capping material, environmental enhancement involving wetland creation/enhancement, sediment cell maintenance, manufactured topsoil, construction fill materials, bricks, ceramics, cement, blocks, tiles, lightweight aggregates, road sub-base [3–18].

There are many examples of beneficial use for DMs over the world, while there is no noteworthy beneficial use studies of DMs carried out in Turkey, yet. This study is performed in the content of ongoing national project named "(111G036) Marine Dredging Applications and Environmental Management of Dredged Materials (DİPTAR)" started on 1st October 2013 in order to develop sustainable environmental management of DMs across Turkey for the first time considering dumping at sea, upland disposal and beneficial use. Moreover, supplying sufficient data and knowledge for The Ministry of Environment and Urbanization in the preparation of the National Framework for DM management is also objected [19]. It is obvious that some European countries like Italy has qualified DM as a by-product and; thus, managed it as non-waste (Ministerial Decree no. 161/2012-paragraph 3.5) [20]. The term by-product is new for Turkey which is introduced into force by new Turkish Waste Management Regulation in 2015 [21]. The beneficial use of DM as by-product is also on the agenda of Ministry of Environment and Urbanization for Turkey in the context of new (draft) National Legal Framework which will come into force at the end of 2016 about the environmental management of DM.

The aggregates used in concrete production, are obtained from natural sources such as quarries or alluvial rivers. Nowadays, taking into account danger of extinction of natural resources and damage to the environment in the process of supplying natural aggregates, optimization of the usage of aggregate resources and investigation on alternative aggregate sources should be considered [22,23]. With the increase of demand for raw materials in construction industry, DM has a potential to be used in the construction industry as an alternative material regarding environmental and economic issues [23].

Utilization of ready-mixed concrete (RMC) combined with modern construction techniques is crucial for daily life, organized urbanization and strong buildings. RMC industry was firstly appeared in Germany in 1903 while RMC was produced firstly in 1993 in Turkey [24]. According to the statistics of the European Ready Mixed Concrete Organization (ERMCO), 65 million metric tons of RMC were produced in Turkey in 2013 and it was corresponding to 27.8% of the total production of RMC in Europe [25]. In addition, maximum production of RMC was observed in Turkey among European countries in 2013.

1.1. Literature review

Beneficial use of DMs in the construction applications as a fine or coarse aggregate in concrete production have been studied by several researchers [10,11,15–17]. The suitability of DMs in the production of harbour pavement has been investigated by Limeira et al. [10,26]. They have indicated that DMs used in the production of harbour pavement has achieved compressive strength criteria for harbour pavement required by the Spanish Standard [10,26]. Junakova et al. [27] focused on reuse of coarse grained DMs (0–4 mm) in place of natural aggregate and fine grained DMs in place of cement. Results of this study showed that concrete made from coarse grained DMs with 20% substitution is suitable as raw material [27]. Liu et al. [14] have focused on chloride salt content of dredged marine sand for the production of reinforced-concrete. Said et al. [11] aimed to utilize DMs from Rades Harbour for the fabrication of paving block as a partial substitution of silica sand. They have concluded that DMs can be evaluated as fine aggregate in the production of paving blocks and optimum substitution ratio for DM should be 19% [11]. Chen et al. [28] used DMs from the Shihmen Reservoir (Taiwan) to obtain artificial lightweight aggregate (LWA). Based on the results, the properties of the concrete produced with LWA have achieved the criteria for structural concrete [28]. However, beneficial use applications of DMs are very insufficient in Turkey where DMs are dumped at sea as stated previously. This study is the first attempt for the beneficial use of DM as a fine aggregate in the production of RMC in Turkey. By the way, it has a paramount importance to guide and encourage other national beneficial use studies.

1.2. Research significance

The aim of this study is to investigate the beneficial use of untreated and treated marine DMs as an alternative fine aggregate in the production of RMC in terms of technical and environmental

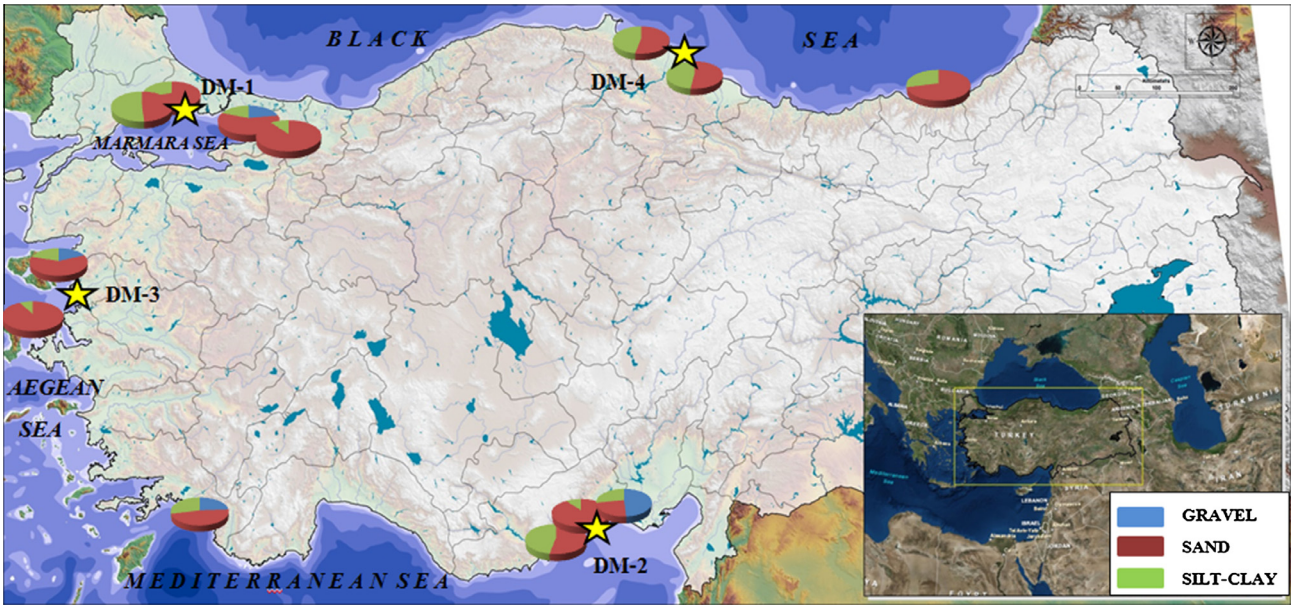

Fig. 1. Four sampling locations of the study with the whole thirteen locations of DIPTAR Project and the pie charts showing the grain size distributions.