SUSTAINABILE CONCRETE IN NUCLEAR STRUCTURES

Ranjan Kumar[1], Kapilesh Bhargava[1], DK Nagori[2], K Srinivas[2], Ankush Sharma[2]

1. Bhabha Atomic Research Centre, Mumbai & Homi Bhabha National Institute, Anushaktinagar, Mumbai, India
2. Bhabha Atomic Research Centre, Mumbai, India

ABSTRACT. Concrete is a global builder and widely used construction material in nuclear structures all over the world. Since long time, concrete has been serving the power, societal and commercial needs of the mankind through means of building the nuclear structures e.g. nuclear power plants, accelerators, radiological laboratories etc. to sustain our progress. The basic materials that comprise concrete are also global and this makes it second to water only in volume consumption. Contribution of concrete in developing the living world is immense and it has unique contribution to how we live both now and in the future. Concrete is having versatile relevance and potential for further exploitation. In the present day scenario, ensuring correct, durable and sustainable applications of concrete, and addressing environmental concern is challenging. Research on sustainable concrete material properties is of great importance. Use of various constituent materials e.g. chemical admixtures of plasticizer/super plasticizer category as well as viscosity modifiers and mineral admixtures like fly ash and silica fume, high performance concrete has resulted into production of sustainable concrete The present paper summarizes the development of use of sustainable concrete in nuclear structures in India.

Keywords: Sustainability, Concrete, nuclear structure.

Dr Ranjan Kumar is a Scientific Officer/F in Civil Engineering Division, Bhabha Atomic Research Centre, Mumbai, India and PG teacher at Homi Bhabha National Institute, Mumbai, India. Telephone:02225593062 Email Id: ranjancv42@gmail.com.

Dr Kapilesh Bhargava is a Scientific Officer/H, Nuclear Recycle Board, Bhabha Atomic Research Centre, Mumbai, India and Professor at Homi Bhabha National Institute, Mumbai, India. Telephone:02225597999 Email Id: kapilesh_66@yahoo.co.uk.

Shri DK Nagori is a Scientific Officer/H and Superintending Engineer in Civil Engineering Division, Bhabha Atomic Research Centre, Mumbai India. Telephone: 02225596158 Email Id: dknagori@barc.gov.in.

Shri K Srinivas is a Scientific Officer/H and Chief Engineer in Civil Engineering Division, Bhabha Atomic Research Centre, Mumbai India. Telephone: 02225595445 Email Id: srinivas@barc.gov.in.

Shri Ankush Sharma is a Scientific Officer/C, Bhabha Atomic Research Centre, Mumbai India. Telephone: 02225593086 Email Id: ankushs@barc.gov.in.

INTRODUCTION

Concrete is invariably used in nuclear industry. In nuclear industry, the main structure is nuclear reactor or a group of reactors together with all associated structures, systems and components necessary for safe generation of electricity. Other nuclear facilities include all nuclear fuel cycle and associated installations encompassing the activities covering from the front end to the back end of nuclear fuel cycle processes and also the associated industrial facilities such as heavy water plants, beryllium extraction plants, zirconium plant, etc.. The major component of nuclear power plant is containment structure which is made of pre stressed concrete. The requirement of containment structure is radiological protection, leak tightness, durability, structural integrity etc. The production of concrete constituents namely cement and aggregate raise environmental concerns. The cement production releases greenhouse gases and the contribution of cement industry to global CO_2 emission is approximately 7% [1]. Aggregate is also responsible for loss of habitat, erosion, sedimentation etc. There is massive consumption of natural resources e.g. water, aggregates etc. There is waste generation from demolition of concrete structures. Construction and demolition waste is also among the primary sources of waste [2]. It affects energy use and environment which is responsible for un-sustainability. There is a need to reduce resource consumption and carbon footprint. Environmental friendly concrete is need of the day.

Replacement of cement and aggregate with alternative materials will create sustainable concrete. Aggregate replacement can be done with recycled concrete aggregate, agricultural and industrial wastes, recycled waste, lightweight aggregate, wastes obtained from demolition etc. The usage of sustainable concrete solves many problems like cost reduction, waste disposal, conservation of natural resources and protection of environment etc. The performance, durability, strength and service life of sustainable concrete need to be evaluated before their use. Identification of alternative constituents of concrete requires extensive studies, preparation of trials mixes of concrete and testing. In the present paper, development and use of sustainable concrete in nuclear industry is highlighted.

CONCRETE IN NUCLEAR STRUCTURES

Concrete is used in nuclear industry because of a number of advantageous properties it has; mould-ability, easy manufacturing process, usage of mainly locally available ingredients, relatively less production cost, good strength in compression, good shielding property against radiation especially gamma radiation, etc.

For nuclear facilities, generally four types of concrete are used namely normal density concrete, heavy density concrete, high performance concrete and self compacting concrete. Concrete ingredients are normally cement, mineral admixtures, chemical admixtures, fine aggregate, coarse aggregate, water and ice.

Normal density concrete is having density in the range of 22 to 26 kN/m^3 and range of grade of concrete is from M25 to M60. This type of concrete is used for structural members of concrete structures. Temperature of placement is generally specified. Design requirement of concrete is achieved at site.

Heavy density concrete is having density in the range of 36 to 56 kN/m^3. This type of concrete is used to meet the shielding requirement of nuclear structure. Heavy density aggregates obtained from haematite, barites, ilmenite etc., steel/lead shots, steel punching etc. are used to prepare heavy density concrete.

High performance concrete (HPC) is used for specific performance and uniformity requirements e.g. placement and compaction without segregation, early age strength, toughness, service life in severe environment, long term mechanical properties etc. HPC is prepared with addition of acceptable mineral admixtures and suitable ingredients.

Self compacting concrete does not require vibration for compaction and it gets compacted by self weight of concrete. Proper workability of concrete is maintained. Mix design is done to ensure the required workability. Various tests on concrete are conducted for ensuring the desired design parameters.

Design criteria of concrete structures important to nuclear safety are divided into three categories namely radiological protection, serviceability and structural strength. Additionally, leak tightness of the liquid-retaining structures is considered [3].

Concrete ingredients

Cement should be from approved brand confirming to relevant Indian Standard. Mineral admixtures used for production of concrete are silica fume, fly ash, ground granulated blast furnace slag (GGBS), pozzolanas, rice husk ash etc. Tests are conducted on concrete for ensuring proper silica content, loss on ignition and specific surface etc. Uniform blending of mineral admixtures with cement is ensured [4]. Chemical admixtures used for concrete production are plasticisers, super plasticisers, retarding agent, viscous modifying agent etc. Two or more admixtures may be used for same concrete after ensuring interaction and compatibility. Generally, dosages of retarders, plasticizers and super plasticizers shall be restricted to 0.5, 1.0 and 2.0 percent respectively by mass of cementitious materials [4]. A higher value of above admixtures may be used based on performance tests relating to workability, setting time and early age strength. Compatibility of admixture and cement should be ensured. Fine aggregate and coarse aggregate to be used for nuclear facilities should confirm to relevant code [5]. Slag and crushed over burnt brick or tile may be used for plain concrete members [4]. Heavy weight aggregate or light weight aggregate e.g. bloated clay aggregates and sintered fly ash aggregates may also be used after satisfactory data on the properties of concrete made by them [4]. Use of fly ash increases workability, durability and strength of concrete. Silica fume increases strength of concrete.

Fly ash is obtained as a waste product from thermal power stations and industrial plants using pulverized or crushed or ground coal or lignite as fuel for boilers. The fly ash as a pozzolana in the manufacture of and for part replacement of cement, as an admixture in concrete, and products such as fly ash concrete blocks, asbestos cement products, etc, have been used. Use of fly ash not only saves scarce construction materials but also assist in solving the problem of disposal of this waste product. The guidelines for extraction, physical and chemical requirements of fly ash for use as pozzolana for manufacture of cement and for part replacement of cement in concrete have been provided [6]. Addition of fly ash in concrete increases the workability and strength.

Silica fume is very fine non-crystalline silicon dioxide. It is a bi-product of the manufacture of silicon, ferrosilicon from quartz and carbon in electric arc furnace. Silica fume is expensive as compared to fly ash.

High performance concrete with high compressive strength, low shrinkage and high durability are required. High performance concrete for containment structure using silica fume content 7.5 to 10% was established by several trails to meet workability, strength, shrinkage and durability requirements [7]. Finely divided fly ash and silica fume are used for high strength concrete.

SUSTAINABLE CONCRETE IN NUCLEAR STRUCTURE

Due to higher safety concern in nuclear structures, workable and durable high strength concrete is required. Use of chemical admixture such as plasticizer, super plasticizer increases the workability of concrete. High strength concrete is obtained by using mineral admixtures e.g. silica fume, fly ash, granulated blast furnace slag etc. replacing cement partly. Use of chemical and mineral admixtures together can provide high performance concrete (HPC). HPC is characterized by higher strength, workability and durability. Self compacting concrete (SCC) is also used in nuclear structure and this concrete is compacted under the action of self-weight. Performance of concrete in fresh stage is better as compared to normal concrete. Chemical admixture such as viscosity modifying agent is used in case of SCC.

HPC of grade M60 using silica fume was used for Unit 1 of Kaiga dome [7]. Silica fume is used in proportion of 5 to 10% of cement or fly ash content is at least 25% or slag content is at least 50% in a mix [8]. There are two types of fly ash concrete namely low volume fly ash concrete (LVFAC) and high volume fly ash concrete (HVFAC) where cement replacement levels are 10-40% and 40-50% respectively. High volume fly ash concrete with 40% to 50% cement replacement is used with sintered fly ash light weight aggregates for production of M45 concrete for nuclear power plant structure in Soffolk, UK. This resulted in to huge cost savings. In many Indian nuclear power plants (NPP), both LVFAC and HVFAC were used with cement replacement level of 24-40% for safety related structural concrete and 40-50% for non structural concrete respectively [9]. Self compacting concrete with high volume fly ash has been used in Indian NPPs. Use of fly ash concrete make the concrete sustainable.

CONCLUDING REMARKS

The paper suggests that concrete for construction of nuclear structures needs to be durable, achieved following sustainable practices. Different options that may be followed, which fit within this are considered, including, cement selection, material proportioning and the use of mineral admixtures are reviewed.

The paper concludes by providing an indication of how both durability and sustainability can go together simultaneously. Use of various constituent materials e.g. chemical admixtures of plasticizer/super plasticizer category as well as viscosity modifiers and mineral admixtures like fly ash and silica fume, high performance concrete has resulted into production of sustainable concrete. Development of use of sustainable concrete in nuclear structures in India has been summarized.

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