International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 2, Volume 2 (February 2015) www.ijirae.com

Measures Adopted to Safeguard Durability of Concrete due to Acidic Environment in Hydro Electric Project – A Case Study

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Abstract*— Generally, concrete will perform satisfactorily on exposure to various hydro and soil environment. However, exposure of concrete to acidic environment weakens it due to various reasons. Concrete is susceptible to acid attack because of its alkaline nature. The acid may be formed due to the products of combustion of many fuels, sewage collection under certain conditions, water drainage from some mines and some industrial waters etc. Acid attack occurs from substances that yield H^+ ions in solution by dissociation. In general, the portland cement does not have good resistance to acid attack. The weak acids however can be tolerated if the exposure is occasional. The components of the cement paste break down during contact with acids. The rate of acid attack depends on the amount of H^+ ions formed, the solubility of so formed Calcium salt etc. The deterioration of concrete by acids is primarily the result of a reaction between these chemicals and the Calcium Hydroxide of the hardened portland cement. In most reactions, the chemical reaction results in the formation of water soluble calcium compounds that are then leached away by the aqueous solutions. In case of sulphuric acid attack, additional or accelerated deterioration takes place because of the formation of calcium sulphate, If the acid or the formed salt solutions are able to reach the reinforcing steel through cracks or pores in the concrete it will corrode the steel causing additional damage to the concrete. In this paper, the case study of Myntdu Leshka Hydro Electric Project, Meghalaya has been presented. The pH of the water of tributaries in the catchment area is found to be acidic which will affect the quality of concrete in future. The extensive study has been carried out to design the concrete mixes to be adopted during construction in order to increase the durability of concrete.

***Keywords*— Chemical environments; Deterioration of concrete; Myntdu Leshka; Ameliorative measures; pH.**

I. INTRODUCTION

If the hydro-environment happens to be acidic, in long run the performance of hydro power projects get affected predominantly due to chemical nature of water. It will erode the concrete as well as corrode the reinforcement causing weakening of the structure. Corrosion of reinforcement has been established as the predominant factor causing widespread premature deterioration of concrete construction worldwide, especially of the structures located in the acidic environment. After initiation of the corrosion process, the corrosion products (iron oxides and hydroxides) are usually deposited in the restricted space in the concrete around the steel. Their formation within this restricted space sets up expansive stresses, which crack and spall the concrete cover. This in turn results in progressive deterioration of the concrete. In general concrete does not have good resistance to acid attack but properly designed rich concrete may tolerate acids of low concentration. In case of Myntdu Leshka Hydro Electric Project, Meghalaya, due to the presence of acidic water of tributaries in the catchment area, the options are to abandon the project or to evolve the ameliorative measures to combat the effect of acidic environment on quality of concrete in future. Therefore, dealing with the problem of acidic environment during post construction phase, high performance concrete has been properly designed after extensive studies.

Myntdu –Leshka HE Project, Meghalaya is a 59m high concrete dam constructed across River Myntdu at Jaintia Hills about 120 Km from Shillong (Fig. 1). A power House of 84 MW (2x42 MW) installed capacity located at the toe of the dam. The river Myntdu originates in Jaintia Hills near Jowai town and called as Mih Myntdu which flows towards the south. In its course, the river meets two tributaries Umsham from west and Lamu from east to form a tri-junction (Fig. 2). The Myntdu river starts with pH value of 6.77 at the sources near Jowai. The pH value recorded after the confluence of Umshang and Lamu with Myntdu is less than 5.0 at the proposed dam site. The Makjai river has pH value more than 6.0 in the right bank while other tributaries Umashang and Ampling have a very low pH (around 2.50) in the left bank all the tributaries / nallah have very low pH values ranging from 2.75 to 5.0.

II. SOURCES OF ACID CONTAMINATION

Water draining from some mines and industrial outlets may contain or form acids, which attack concrete.

- Peat soils may contain iron sulphide (pyrite) which, upon oxidation, produces sulphuric acid. Further reaction may produce sulphate salts, which can produce sulphate attack.

- Mountain water streams are sometimes mildly acidic, due to dissolved free carbon dioxide. Usually this water attacks only on the surface if the concrete is of good quality. However, the some mineral water containing large amounts of either dissolved carbon dioxide or hydrogen sulphide, or both, can seriously damage any concrete. In the case of hydrogen sulphide bacteria that convert this compound to sulphuric acid may play an important role.
- Organic acids from farm silage, or from manufacturing or processing industries such as breweries, dairies, canneries, and wood pulp mills, can cause surface damage.
- The products of combustion of many fuels contain sulphurous gases, which combine with moisture to form sulphuric acid.
- Sewage may be collected under conditions, which leads to acid formation.

Fig. 1: Location map of Myntdu –Leshka HE Project, Meghalaya

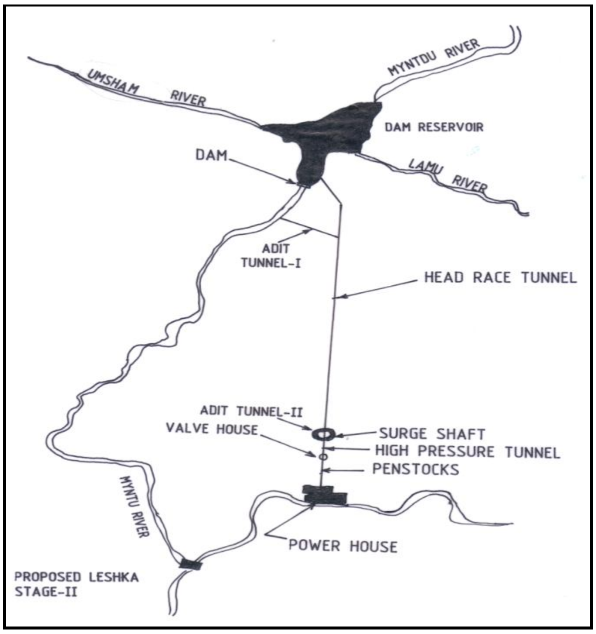

Fig. 2: Layout map of Myntdu –Leshka HE Project, Meghalaya

In case of Myntdu –Leshka HE Project, it has been observed that the tributaries having low pH are located in proximity of the coal mining and coal dumping area in the catchment area (Fig. 3 & 4). Water flowing over coal refuse piles, dumped coal mine are typically acidic with slightly elevated levels of dissolved metals. These are also commonly known as Acidic Mine Drainage (AMD). The formation of AMD is primarily a function of geology, hydrology and mining technology employed. AMD is formed by series of the complex geo-chemical and microbial reactions that occur when water comes in contact with pyrites in coal, its waste residue or the overburden of a mine. The resulting water is usually high in acidity and dissolved metals. The metals stay dissolved in solution until the pH raises to a level where precipitation occurs. The summary reaction is as follows:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3 + 8\ H_2SO_4$$

Fig. 3: Extraction of coal by "Rat-hole" mining

Fig. 4: Stagnated water in abandoned mine

III. CONCRETE IN ACIDIC ENVIRONMENT

It is a common knowledge that concrete is basically alkaline in nature and acids cause considerable damage. The deterioration of concrete by acids is primarily the result of reaction between these chemicals and the calcium hydroxide of the hydrated portland cement. Reaction between these two is simple in nature and not complex as those that take place during sulphate attack, resulting in expansion and cracking of the concrete. Acidic water simply dissolves the more soluble constituents of the set cement and forms water-soluble calcium compounds which are then leached away by the aqueous solutions, destroying its crystalline structure and leaving the residue having low strength. The extent to which attack may occur is influenced by a number of factors, the most important of which are permeability of the concrete, the conditions to which it is exposed and the type of cement used. The quality of the concrete placed also influences the severity of any attack. The action on impermeable set cement mass may be so low and to a limited depth only. Serious damage may occur in permeable concrete which allows acid solutions to penetrate more deeply. When concrete subjected to pressure from acidic water on one side and exposed to air on the other side, aggressive action more severely. Portland cement concrete is more vulnerable to attack, since it contains higher proportion of Calcium Hydroxide released during hydration of Calcium Silicates. It is also known that calcareous aggregate in concrete are prone to acids attack but siliceous aggregates are resistant to most acids and other chemicals and are sometimes specified to improve the chemical resistance of concrete.

In brief, the possible deleterious effects on concrete are;

- The cement compounds are eventually broken down & leached away from concrete
- With the Sulphuric acid attack, calcium sulpho-aluminate formed which on crystallization can cause expansion and disruption of concrete
- Loss of concrete strength is possible over a period of time
- Possibility of attack on metallic portion e.g. turbine blades, reinforcement etc.

IV. MIX DESIGN CONSIDERATIONS

As per exposure conditions given in Indian Standard code IS456: 2000, the general environment to which the concrete will be exposed during its working life is classified into five levels of severity i.e. mild, moderate, severe, very severe and extreme. In case of Myntdu –Leshka H E Project, the concrete is directly in contact with aggressive chemicals i.e. acidic environment which falls under the extreme environmental exposure condition.

As per Table-5 of IS: 456-2000, the concrete requirements for Extreme Environmental Conditions are as follows:

- **Plain Concrete:**
  - Minimum Cement content kg/m^3 : 280
  - Maximum free water cement ratio : 0.40
  - Minimum grade of concrete : M25
- **Reinforced Concrete:**
  - Minimum Cement content kg/m^3 : 360
  - Maximum free water cement ratio : 0.40
  - Minimum grade of concrete : M40

These criterions have been taken in to consideration while analyzing the mix design works.

According to standard practices, there are essentially three ways to improve concrete's resistance to acids, (1) choosing the right concrete composition to make it as impermeable as possible, (2) isolating it from the environment by using a suitable coating or (3) modifying the environment to make it less aggressive to the concrete.

In present study, the fundamental principle of increasing chemical resistance by lowering concrete's permeability was used to optimize concrete mix designs. The objective was to keep the erosion rate so low that a service life could be achieved. According to research developments, it was found that a significant improvement in acid resistance can be achieved by carefully controlled use of fine supplementary cementitious materials i.e. slag, fly ash, silica fume etc. The use of blended cements also increases acid resistance. The main reason for the increased acid resistance of the concrete investigated was the formation of a very dense hardened cement paste and aggregate interface with very low porosities.

V. EXPERIMENTAL PROGRAM

This study was undertaken to evolve the concrete mixes to resist the destructive action of acidic water, for this purpose Ordinary Portland cement and also Portland Pozzolana cement and micro silica in different proportions were used at different locations.

A. ***Properties of Ingredients***

The properties of concrete are significantly influenced by the basic properties of constituent materials. Micro silica was used as it provides dense microstructure and low permeability to concrete (Fig. 5). It also improves other properties of hardened concrete. Therefore, the preliminary properties of Ordinary Portland cement, Portland Pozzolana cement, fine aggregates, coarse aggregates, micro silica, admixture and mixing water are evaluated according to relevant codes. Care has been taken to ensure that the same type of OPC, PPC, micro silica, fine and coarse aggregates were used throughout this investigation.

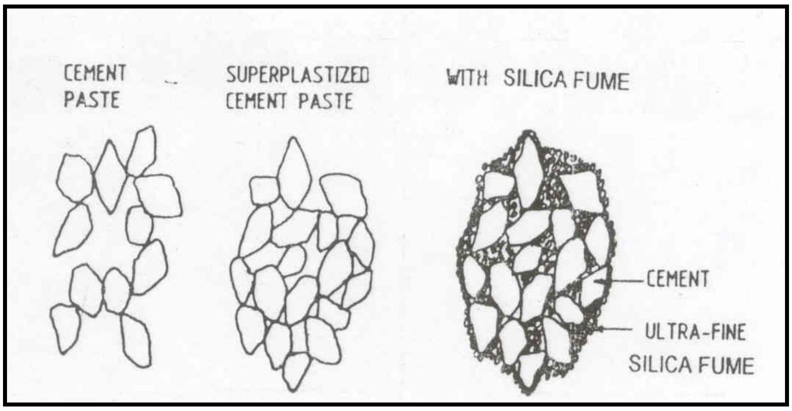

Fig.5: Dense microstructure of concrete due to use of micro silica

1) ***Cement*****:** The cement used throughout the test programme was OPC (43 grade) confirming to IS: 8112-1989 and PPC confirming to IS: 1489 (Part I)-1991. The chemical and physical properties of the cement were tested as per the IS: 4032-1985 & IS: 4031-1988 respectively.

2) ***Micro Silica*****:** Micro silica used in this study was obtained from reputed firm in India. This Micro Silica conforms to the requirement of ASTM C1240 and IS: 15388-2003.

3) ***Superplasticizer*****:** High range water reducing admixture called as super plasticizers are used for improving the flow or workability for lower water-cement ratios without sacrifice in the compressive strength. This super -plasticizer is available with standard specifications of ASTM C 494 Type G and IS: 9103-1999.

4) ***Fine aggregate*****:** The fine aggregate used was natural sand without any organic impurities and confirmed to IS: 383-1970. The fine aggregate was tested for its physical requirements as per relevant IS 2386 (Part I to VII)-1963.

5) ***Coarse aggregate*****:** Properties of the aggregates which influence the properties of both the fresh and the hardened concretes have to be considered when the concrete is proportioned. The coarse aggregate was tested for its physical properties as per relevant IS 2386 (Part I to VII)-1963.The coarse aggregate used for this investigation was crushed rock from Lamu quarry confirmed to IS: 383-1970 only for non wearing surfaces.

6) ***Water*****:** Water used for mixing and curing was tested as per IS : 3025 – 1964 and IS: 456 – 2000.

VI. MIX DESIGN PROCEDURE

The main object of concrete mix design is to select the optimum proportions of the various ingredients of concrete which will yield fresh concrete of desirable properties like workability and hardened concrete possessing specific characteristic compressive strength and durability.

Besides these requirements it is essential that the concrete mix is prepared as economically as possible by using the least possible amount of cement content per unit volume of concrete, with due regard to the strength and durability requirements as per IS 456-2000. Since concrete is produced by mixing several discrete materials, the numbers of variables governing the choice of mix design are necessarily large.

The concrete mix proportions were calculated as per IS 10262-2004. The trial mixes for pumpable concretes were performed to arrive at the required mix proportions for using it in Tunnel & Power House works. During trials, slump was measured and the water content and dosage of admixture are adjusted for achieving the required workability based on trial and error method. The mix proportions are reworked for the actual water content and checked for durability requirements.

A. ***Preparation of Specimens***

The cube specimens of size 150 mm x150 mm x150 mm were cast as per procedure laid down in IS: 516 -1959 (Reaffirmed 2004) for each mix of concrete to determine the compressive strength. These specimens were air dried for 24 hr before they were cured for 7 and 28days for performing compressive strength test.

B. ***Curing of the Specimens***

The specimens were removed from the moulds after 24hr from the time of adding the water to the ingredients. The specimens then marked for identification. These specimens were then stored in water for the required period of curing.

C. ***Compressive Strength Test Procedure***

Compressive strength of a material is defined as the value of uni-axial compressive stress reached when the material fails completely. In this investigation, the cube specimens of size 150 mm x 150 mm x 150 mm are tested in accordance with IS: 516 – 1969.

VII. RESULTS & DISCUSSION

Concrete mix design was carried out for pumped concrete mixes of Grade of concrete M25 A20, M30 A20, M35 A20, M25 A20 using OPC 43 Grade with Micro silica & M20 A20 & M25 A20 using Portland Pozzolana cement keeping in view extreme exposure conditions due to low pH and suitability of available aggregates for non wearing surfaces and also depending on the site specific requirements. For each grade of concrete, 5 trials (of 6 cubes each) have been carried out using varying cement content, micro silica content and admixture content to arrive at the required concrete mixes. The Recommended mix proportions for various grades of concretes are given below in Table 1 and Table 2:

TABLE 1
Concrete made using OPC, 43 Grade cement and micro silica

Description of concrete Mix	**M25 A20**	**M30 A20**	**M35 A20**	**M40 A20**
Cement used	OPC, 43 Grade	OPC, 43 Grade	OPC, 43 Grade	OPC, 43 Grade
Mix proportions (By wt.) C:FA:CA	1:1.683:3.068	1:1.683:3.068	1:1.683:3.068	1:1.287:2.453
Cement contents (Kg/m^3)	350.0	350.0	350.0	425.0
Microsilica Contents, Kg/m^3	28.0	28.0	28.0	34.0
Water Cementitious Ratio	0.45	0.45	0.45	0.38
WRA % by wt of Cementitious	1.75	1.75	1.75	1.75
AER% by wt of Cementitious	0.04	0.04	0.04	0.04
Slump observed , mm	170 mm	170 mm	170 mm	140 mm
Compressive Strength at 7 days	317.0	317.0	317.0	345.0
Compressive Strength at 28 days	461.0	461.0	461.0	545.0

TABLE 2
Concrete made using PPC cement without micro silica

Description of concrete Mix	**M20 A20**	**M25 A20**
Cement used	PPC	PPC
Mix proportions (By wt.) C:FA:CA	1:1.886:3.498	1:1.886:3.498
Cement contents, Kg/m^3	350.0	350.0
Microsilica Contents, Kg/m^3	Nil	Nil
Water Cement Ratio	0.45	0.45
WRA % by wt of Cement	1.75	1.75
AER% by wt of Cement	0.04	0.04
Slump observed, mm	130 mm	130 mm
Compressive Strength at 7 days	179.0	179.0
Compressive Strength at 28 days	345.0	345.0

A. ***Concretes with Micro Silica***

The concrete mixes M25 A20, M30 A20, M35 A20, M25 A20 were produced using micro silica by partially replacing cement with SF at different percentages of 5 and 8% by weight of cement. It was observed that the compressive strength increased with percent increase in replacement levels of SF i.e. 5% to 8% respectively. The improvement in compressive strength was higher at the age of 28 days with the addition of silica fume up to 8% compared to 7 days strength.

B. ***Concretes with PPC Cement***

The concrete mixes M20 A20 & M25 A20 were produced using PPC cement only. The results of relative compressive strength of all micro silica mix concretes at different ages (7d, 28d,) and PPC cement reveals that the concrete containing micro silica is better than the concrete using PPC.

The results encourage the use of micro silica as pozzolana material for partial cement replacement in producing high durable concrete.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn within the scope of this research work:

- The strength of concrete increased with the increase of SF content in all the silica fume mixes at both early and later ages.
- The silica fume mix concrete with partial replacement up to 8% SF exhibited slightly higher compressive strength as that of both OPC and PPC mixes concrete at all ages.
- The silica fume binary concrete with partial replacement up to 8% SF exhibited better performance against underwater abrasion resistance as that of OPC concrete at all ages.
- The silica fume mix concrete with partial replacement up to 8% SF exhibited decreased ASR expansion compared to OPC concrete. However none of the compositions tested produced 14-day expansions less than 0.1% after 14 days of exposure.

Recommended remedial measures suggested are;

- Good dense concrete
  - Preference to be given to blend cements namely Portland Pozzolana Cement or Portland Slag cement (with Minimum slag constituent of 50%) or Silica fume - OPC concrete
  - Lower water cement ratio- recommended water cement ratio shall strictly be followed to achieve required compressive strength as well as low permeability.
- Adequate protection of reinforcement with good concrete cover
- Non –corrosive steel or coating; chemical inhibitors; or cathodic protection are useful remedial measures for protecting reinforcement
- Use good quality turbine blades, which can withstand acidic environments under too much high pressure.

ACKNOWLEDGEMENTS

The authors extend their sincere thanks to MeSEB, Meghalaya Authorities for their cooperation in the field investigations. We extend our sincere thanks to one and all in Concrete Discipline for the timely help extended by them. We extend our sincere gratitude to officials from MeSEB Laboratory, Meghalaya for their valuable efforts and timely help. Sincere gratitude are extended to all the authors whose publications provided us directional information from time to time.

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