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Durability of Concrete in the Arabian Gulf

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Abstract: The gulf region is currently witnessing an extensive urbanization development and billions of dollars are being spent on reinforced concrete construction projects. It is estimated that the present projects being executed in the Gulf States are in the range of 800 billion Dollars. By 2020, six of the tallest ten buildings in the world would be in the region. These mega projects will not only exert pressure on resources but will also require high performance materials, top project management and greater quality control. All over the region, there are many concrete structures which are in outstandingly good conditions compared to their age, but there are also examples of structures that deteriorated to poor conditions within a few years. Many reinforced concrete buildings exhibited some signs of distress early in their service life. Awareness of the importance of concrete durability has risen in the region alongside the need to stretch concrete to its uttermost limits. In many parts of the Middle East, there are important factors such as unskilled workmanship, deleterious substances, funds and speed of construction that influences the durability of structures and bridges to a great extent. Considering the hot and arid weather of the region and the need to use high-strength concrete brings forward the problem of concrete durability in hot weather. It can be seen that concrete structure tends to deteriorate more rapidly exhibiting greater problems with cracking control than those in temperate regions of the world. Maintenance in the Middle East has consistently been treated as a secondary activity in the construction industry, attracting only a minimal recognition of its importance. However, in recent years, maintenance has gained greater attention since its being looked to as a tool towards sustainability and a means toward the conservation of the construction stock. In the present paper, a brief summary of research and issues related to durability, hot weather concreting, sustainability and maintenance will be presented. Results of an investigation on the effect of hot weather on cracks and non-destructive testing will be also elaborated.

Key words: Durability, hot-weather concreting, sustainability, maintenance.

1. Introduction

The Gulf Region has experienced significant growth in construction where reinforced concrete is mostly used. The environment of the Gulf region has an impact on concrete structures as it is one of the most aggressive exposure conditions for the durability of reinforced concrete structures in the world as it tends to deteriorate more rapidly due to high ambient temperature, low relative humidity, salt-contaminated dust, sea water and underground salts, corrosion of reinforcement and sulfate attack, unless particular precautions are taken. In spite of extreme environmental conditions in the Gulf Region, not all buildings deteriorate or become unserviceable after a short period of operation. Numerous buildings have survived for 30 to 40 years and more without major maintenance or repair. The concrete structures design should stand on the evaluation of the local environmental conditions and on the effects of hot climate on the structure rather than on general environmental conditions of a vast area. The design must consider weather, topography, geography and so on for the immediate-surrounding conditions.

To understand the importance of concrete durability, durability should be defined as it is: the resistance of concrete to weathering action, chemical attack, abrasion and other degradation processes. Concrete deteriorates to some extent over time; to ensure adequate durability, deterioration rate should be minimized. Therefore, concrete durability is related to specification of materials, design process, construction practices, quality of workmanship, environmental effects and quality of defects repair.

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2. Durability and Hot Weather in the Arabian Gulf

2.1 Weather Conditions and Environmental Effects on Concrete Structures in the Arabian Gulf

The Arabian Gulf Region does not have a uniform environment as the climate and environment of the countries vary significantly from one region to another so one country cannot generalize the climate characteristics for the whole area. There are clearly apparent differences in temperature, humidity, rain, wind, geology of soil and raw materials in the Arabian Gulf Region. The region can be differentiated by two climatic zones which are 'Hot-Dry' and 'Hot-Humid' zones as illustrated in Fig. 1 [1]. Temperatures can vary by as much as 30 °C, and the relative humidity may range from 40 to 95% during a typical summer day. The minimum to maximum temperature range is from 3 to 50 °C, and the relative humidity may be as high as 95% or as low as 5%. The combination of these values result in exposure conditions that are very detrimental to concrete materials, members and structures. These exposures cause damage due to thermal and mechanical stresses [2].

The main challenges that face reinforced concrete construction in the Gulf region are hot-humid, hot-dry and salty environments. In warm climate high ambient temperature affects concrete structures as heat is a driving energy source that accelerates the deterioration mechanisms progress. The classical law connecting heat and the rate of chemical reactions states that for each increase of ten degrees Celsius in temperature, the rate of chemical reactions is doubled [3].

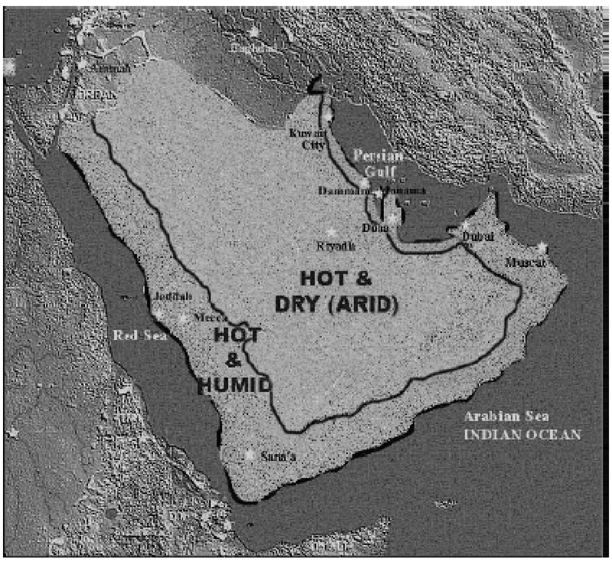

Fig. 1 Hot-Dry and 'Hot-Humid' Zones of the Arabian Peninsula.
Source: (http://cipremier.com/100032012).

Many researches on the corrosion problem have been published in the Arabian Gulf. These researches showed that most of the problems of corrosion of existing structures were due to low-quality materials and severe environmental conditions combined with poor design and construction practices and also due to poor mix design and a lack of quality control in the field. Moreover, for concrete durability in the Gulf, the weather is the worst in the world. For that reason, it is uncommon to see structures survive their intended service life.

2.2 Water Issues

Development in the Arab region is intimidated by water scarcity issue as the area has a variable low rainfall with high evaporation rates and frequent droughts. These factors contributes to low availability of water resources and reliability. While water resources are in short supply, demand for water is growing in the GCC countries. The major causes of increasing water demand include population growth and rapid urbanization, besides wasteful consumption patterns both in domestic and agricultural sectors. All the countries in the region have high levels of urbanization, more than 84% in most cases. Water consumption in these countries ranges between 300-750 liters per person per day, which ranks among the highest in the world. For this reason, the saving of water for the construction industry is a must and a major challenge for engineers. Overcoming the problem of using water in construction can be achieved by using high performance concrete and self-curing concrete.[4]

3. The Environment and Sustainability Issue

Reducing the environmental impact of the concrete structure is taking a place in all environmental studies and developments as the construction industry has a significant negative impact on the environment starting with harvesting raw materials, transporting and manufacturing to the actual construction of the required concrete structure. According to the Department of Energy (DoE), building devour energy more than factories and automobiles.

Construction is considered one of the main consumers of resources and energy. Although it generates work and the need for more labor, cement - the major construction material - generates large amounts of CO_2 and hence causes a great damage to our environment. With increase in the value of land, real estate agents demand more utilization of land. The architects and planners should not bend to the demands of restricting the designs to aesthetic values and speed of construction only, but should consider and insist on the social and environmental aspect of their design and planning. With the rising increase in local economies, there is a demand for faster construction, and little concern for quality and durability. More than 40% of global energy use and one-third of global greenhouse gas emissions are from buildings, in developed and developing countries. The largest potential for delivering long term, significant and cost-effective greenhouse gas emissions comes from Buildings. The energy consumption in new and existing buildings can be estimated to be 30 to 80 percent with a potential net profit during the building lifespan. Moreover, as buildings have a relatively long lifespan, actions taken now will continue to affect their greenhouse gas emissions. Actions have been taken in most of the developed countries and in many developing countries in the direction of reducing greenhouse gas emissions from the Buildings, however, these actions have a limited impact on the actual emission levels. Reduction of greenhouse gas emissions coming from buildings will bring several benefits to the economy and to the society.

Environmental issues are getting attention worldwide. These issues include, not only updating the rules and regulations that enforce sustainable development, but also the economic incentives to incorporate sustainable development designs. The natural ecosystem has become a focal point for urban planning within the past generation, planners of earlier periods tended to regard the environment as being rural or as a “wilderness”, hence, this was not applicable to city choices except perhaps in the layout of parks. The news media began to publicize environmental concerns nationally, and the resulting public awareness spurred major legislation, which empowered planners to incorporate ecological values.

Environmental policy now has several dimensions with distinct challenges. The first is that a city, like a human body, has a “metabolism” by which it takes in means of life support and disposes of unneeded and harmful products. In practical terms, this points to the supply of air, water, food, energy and raw materials for manufacturing and the safe removal or reprocessing of wastes. While much of this exchange is conducted by the private market, it impacts how land is used and so falls under public regulations. In the past century, resources were constantly being used, especially energy. The environmental impact of ever-increasing usage is rapidly becoming a major factor, and if we don’t change our energy usage, the costs could be enormous for future generations. Current construction methods result in our buildings being a major user of energy, not only in their construction, but also in their day-to-day operation. Continuing future growth of energy usage will have to reduce if we hope to obtain a sustainable habitat on our spaceship, planet earth. Building activity, the production, maintenance and repair of the building environment has a significant impact on the environment representing half the total energy consumed in high consuming countries. Notwithstanding, the acknowledged need to conserve resources, the rate consumption is increasing. It could be argued that the increase is a direct consequence of the political agenda of all governments to increase the affluence of their peoples. Affluence and consumption are at the core of the sustainability agenda. That agenda is concerned with understanding the impact of human activity on our environment and from a position of knowledge, it moves toward a position where human activity is sustainable [5]. Construction is considered one of the main consumers of resources and energy. Although it generates work and the need for more labor, cement - the major construction material - generates large amounts of CO_2 and hence causes a great damage to our environment. With increase in the value of land, real estate agents demand more utilization of land. The architects and planners should not bend to the demands of restricting the designs to aesthetic values and speed of construction only, but should consider and insist on the social and environmental aspect of their design and planning. With the rising increase in local economies, there is a demand for faster construction, and little concern for quality and durability. More than 40% of global energy use and one-third of global greenhouse gas emissions are from buildings, in developed and developing countries. The largest potential for delivering long term, significant and cost-effective greenhouse gas emissions comes from Buildings. The energy consumption in new and existing buildings can be estimated to be 30 to 80 percent with a potential net profit during the building lifespan. Moreover, as buildings have a relatively long lifespan, actions taken now will continue to affect their greenhouse gas emissions. Actions have been taken in most of the developed countries and in many developing countries in the direction of reducing greenhouse gas emissions from the Buildings, however, these actions have a limited impact on the actual emission levels. Reduction of greenhouse gas emissions coming from buildings will bring several benefits to the economy and to the society.

In the Arabian Gulf, 70% of energy is consumed by buildings in some parts of the Gulf compared to 40% consumed worldwide. The Reason for this high energy consumption might be the use of glass skyscrapers and brutally hot conditions. According to the United States Green Building Council, the Middle East has not adopted the green building movement in building structures that emit fewer emissions and consume less water early enough. For the past couple of years, the Middle East has made great progress in the field of green buildings as it has more than 1,200 LEED-registered buildings [6].

For the past few years, environmental friendly and sustainable building has taken a priority in decision makers‘ plan in the gulf regions, like Qatar, UAE and Lebanon as they have published different green building standards and regulations and they have come up with their own green building rating system to incorporate socio-economic, environmental and cultural aspects into modern architecture . But the sustainable construction practices in the region mostly focuses on new construction ignoring the importance of retrofitting the existing buildings as they keep consuming energy resources and increasing the emission of greenhouse gases. Qatar’s Global Sustainability Assessment System (GSAS) is billed as the world's most comprehensive green building rating system while Abu Dhabi's Pearl Rating System (PRS) has carved a niche of its own in global green buildings sector [7].

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United Arab Emirates and Qatar are currently leading the sustainability movement in the region, as they have the highest number of green buildings in the Middle East and North Africa [9]. There are about 1,200 green buildings in MENA that have a Leadership in Energy and Environmental Design accreditation. And 65% of these buildings (802 building) are located in the UAE. Also, 14.5 % of these buildings are located in Qatar (173 green buildings), 12% are located in Saudi Arabia (145 green buildings), 2% in Lebanon (25 green buildings) and 1.8 % in Egypt (22 green buildings) [10]. There are about 1,200 green buildings in MENA that have a Leadership in Energy and Environmental Design accreditation. 65 % of these buildings (802 building) are located in the UAE. 14.5 % of these buildings are located in Qatar (173 green buildings), 12% are located in Saudi Arabia (145 green buildings), 2% in Lebanon (25 green buildings) and 1.8% in Egypt (22 green buildings) [8].

Some of the notable examples of green buildings in the Middle East are: (1) Masdar City in Abu Dhabi, (2) KAUST in Saudi Arabia and (3) Msheireb Downtown Doha in Qatar.

The UAE is getting stricter on the environment friendly side to development,more so, because of the rapid scale of development in so short a time -just 30+ years. Development which sometimes has been at the cost of the environment, which is every country's every region's natural heritage. A fast growing population, immense financial resources and an ambitious development program have combined to place strong pressures on the environment in the UAE. The growing consensus from major industry analysts is that technological innovation, if engineered in an environmentally- conscious way, brings both reduced costs and increased efficiencies to their operations. Institutions across the Middle East are recognizing that environmental protection laws can actually help to drive positive economic growth. However the practical meaning of sustainability is open to much debate. At minimum, it is a call for steady reduction of air and water pollution, reduction of and recycling of wastes, more efficient use of energy and a shift to renewable energy sources, and restraint in the development of rural land [8].

Dubai is home to one of the region’s first green shopping malls and an eco-friendly mosque was built in 2013, many other examples can be found. In Abu Dhabi, Masdar Institute, the world’s first graduate-level university dedicated to providing real-world solutions to issues of sustainability was established. The Institute’s goal is to become a world-class, research-driven, graduate-level university, focusing on advanced energy and sustainable technologies. Masdar City promises to be a model for green cities all over the world. Qatar’s goal to reach the leaders of sustainability in the world was started in 2010 by Msheireb Downtown Doha, which promises to be the world’s largest sustainable community with 100 buildings using an average of one-third less energy. Another project is Lusail City, a planned development for nearly 200,000 people on the edge of Doha, has promised to adhere to the country’s voluntary green building guidelines which set standards for everything from water consumption to traffic congestion.

If the green building technologies were used in the Middle East instead of the usual technologies, environmental problems will be tackled significantly in addition to the long term financial returns. In terms of overall sustainability, the MENA region is still considered as being far behind compared to other markets, but in the next 3 years, 29% of companies in this region would have over 2 million square feet of green projects planned, which is the highest of any region [8].

4. Construction and Durability Issues

Until the 19th century, buildings of over six stories were rare. It was impractical to have people walk up so many flights of stairs. Also, water pressure could only provide running water to about 50 feet (15 m). The development steel, reinforced concrete, and water pumps have made possible the construction of extremely tall buildings, some of which are over 300 meters tall. The other development essential to practical skyscraper development was the invention of the elevator. Considerable efforts were introduced to improve design and construction procedures to address typical problems encountered in high-rise residential buildings. They found ways to upgrade parking garages, enhance envelope durability and improve a multi-unit building's thermal envelope, improve HVAC systems, accessibility and environmental performance. But one of the most important achievement is the enhancement of steel and reinforced concrete to cope with the ever increasing demand for fast and long lasting construction.

UAE is witnessing an extensive urbanization development and billions of dollars are spent on reinforced concrete construction projects. Many reinforced concrete buildings exhibited some signs of distress early in their service life. Awareness of the importance of concrete durability has risen in the region, however, repair techniques are essentially those involving short-term control of the situation and use of imported systems which are not fully tested [8]. What is meant by a durable structure is in practice very subjective and difficult to define precisely. It should refer to a structure maintaining a satisfactory performance over a predetermined period of time without requiring unexpected high costs for maintenance. Therefore, the term SLD (Service life design) has replaced the term durability, being a quantifiable and measurable quantity (in years). In principle too, basically different design strategies to ensure a required service life can be followed: Strategy A: avoid the degradation threatening the structure due to the type and aggressiveness of the environment; Strategy B: select an optimal material composition and structural detailing to resist, for a specified period of use, the degradation threatening the structure. Schafer [11] emphasized this line of thought.

There have been many advances in concrete technology during the past 25 years. Full advantage will not be derived from these advances unless they can be shown to be appropriate to the environment in which they are to be used and the application and use of basic concrete design and construction techniques is sound. Good performance can only be achieved when designs allow for building ability, ease of construction, and if high standards of supervision and workmanship are used and imposed. Performance is also dependent on the use of appropriate technologies for specific environments, both macro and micro. In the past, there was a tendency for concrete technology developed in Europe and North America to be imported into other parts of the world, with markedly different environments. The resulting poor performance has led to the realization that existing technologies need to be checked out for their effectiveness in specific locations before use.

The problem of concrete durability in hot weather is very complex. It can be seen that concrete structure in the hot, arid environments tends to deteriorate more rapidly than those in temperate regions of the world, unless particular precautions are taken. Increase in temperature also increases the cracks, including plastic shrinkage cracking and drying shrinkage cracking, facilitate the ingress of salt-laden water and moisture causing disintegration of concrete due to sulfates attack and corrosion. Carbonation, which reduces the passive effect of concrete on reinforcement corrosion, proceeds at a faster rate at the higher temperatures. Even good concrete, where chlorides have been included at the mixing stage or have entered from an external source, deteriorates more quickly than it would in a temperate climate. It has been reported that chemical agents, for example, water-reducers retard carbonation, as they promote densification of concrete. On the other hand, mineral admixtures such as fly ash, silica fume and blast furnace slag has been reported to increase the rate of carbonation [12].

In many areas, large quantities of resources are being spent on maintenance and rehabilitation of concrete structures due to lack of durability. There is a great challenge, therefore, for the engineering profession to utilize and further develop the technology of high-strength concrete or high-performance concrete for the benefit of the society. The use of admixtures and additives in the gulf has gained greater interest and acceptance leading to an extensive increase in the amount of concrete which contains admixtures. The climatic conditions and the need to stretch concrete to its ultimate capabilities make the use of admixtures not only necessary but a must. However, engineers in the region are finding themselves grappling with products, standards and specifications which emanate from other countries, and working in climatic conditions which the admixtures have not been tested in. The assumption that an admixture that retards at 21 °C will do so at 33 °C is not valid. Concrete mixtures incorporating fly ash, silica fume, or fine cements frequently have a low to negligible bleeding rate, making such mixtures highly sensitive to surface drying and plastic shrinkage, even under moderately evaporative conditions. Certain admixtures increase the time of initial setting or reduce the amount of water needed for a given initial slump or both, but such concretes may stiffen faster, sometimes too fast even for a cement and an admixture that individually meet all specifications.

It is imperative that government institutes responsible for the construction industry should join hands with the universities to expand the education and implementation of quality control. The cost of raw materials and manufacture of concrete is the same for good and bad concrete, the difference of an additional 5% cost of quality assurance could lead to a saving of more than 70% in life cycle of structures. We should never settle in the Middle East for building to last 30 year but must target for 70 years and more bridges should last more than 120-150 years and important buildings should reach 200-250 years. This is not far-fetched at all, currently, there are structures that are being designed for 250-500 years. The British library was designed to last for 1,000 years and a temple in China was designed to last for 5,000 years.

5. Case Studies

5.1 The Effect of Hot Weather Concreting on Cracking Tendency of Tensile Specimens

Hot weather introduces many problems in producing, transporting, casting, and curing concrete, which can adversely affect the properties of fresh and hardened concrete. Hot weather decreases workability of the fresh concrete mix. It accelerates the rate of stiffening (slump loss), and reduces setting time. Moreover, it aggravates cracking due to plastic shrinkage and due to drying shrinkage.

In some parts of the region, when casting on hot days, water is added to the fresh mix to enhance its workability and to retard its setting. This kind of conduct can, after a short time from finishing, cause a reinforced concrete member in the upper reinforcing bars to be imprinted on its surface and produce long lines of splitting cracks. These plastic cracks may impair the bond strength of those upper bars with the concrete.

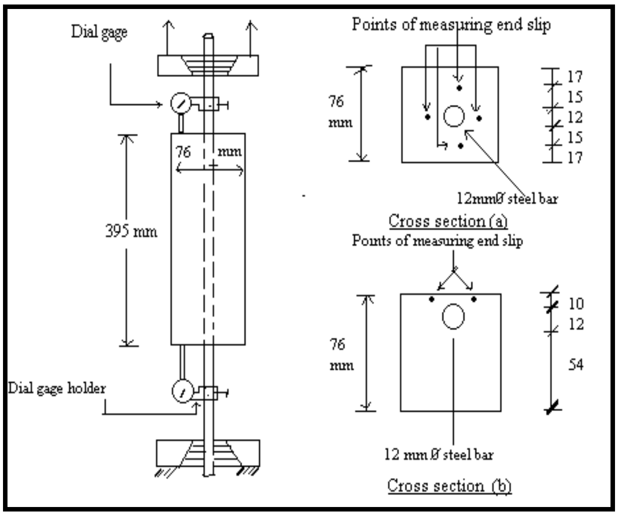
The effect of casting under hot weather conditions on crack width and crack spacing of tensile specimens was investigated. Concentric and eccentric tensile specimens were utilized and end slip and crack spacing were measured during the test. Tests were performed on five concrete mixes with water to cement (w/c) ratios varing between 0.45-0.60. Simulating moderate and high temperature conditions, the tests were performed at ambient temperatures of 20, 40, and 50 $^{\circ}$C, and relative humidities of either 25 or 50%. These observations drew attention to the fact that there is a great interference between the practice of casting in hot weather with the bond strength of concrete and the tendency to crack. Any cracking before applying the load affects the state of stress after applying the loads, and the cracks orientation.

The scope of this research is to investigate the effect of hot weather concreting on the crack width and the crack spacing of tensile specimens. Two types of tensile specimens, concentric and eccentric, were utilized and the end slip and the crack spacing were measured during the test.

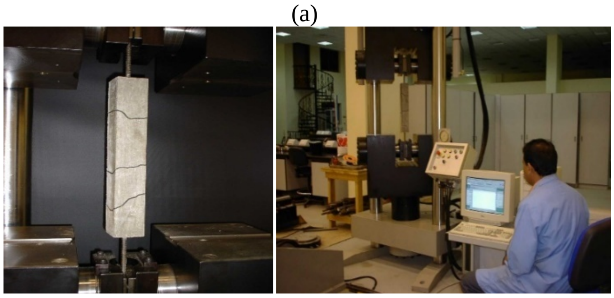
The tests were conducted on 76 × 76 × 395 mm^3 prismatic uniaxial reinforced concrete specimens with a steel bar of 12 mm diameter embedded in the concrete. The steel bar were protruded 250 mm from both ends. The two following types of tensile specimens were tested: (1) Concentric tensile specimens [TC], each reinforced with a concentric steel bar as shown in Fig. 2a. Four [TC] specimens were cast for each series; (2) Eccentric tensile specimens [TE], each reinforced with an eccentric steel bar as shown in Fig. 2b. Two [TE] specimens were cast for each series. In addition, three 100 × 100 × 100 mm concrete cubes were cast from each series to determine the compressive strength. Test results showed that hot weather concreting increased width of cracks in tensile specimens about 20-40% for mixes with low w/c ratio and low slump, on the other hand, crack widths decreased in the range of 30-40% for mixes with high w/c ratio and high slump. No tangible effect on crack spacing was noticed.

5.2 Non Destructive Testing for Concrete Compressive Strength

Nondestructive testing is a useful and practical approach to determine the in-situ compressive strength of concrete. It is used as a measure for quality, as well as to determine uniformity of materials in existing structures. In practical applications, nondestructive testing can be utilized to calculate the relative compressive strength and to provide guidelines for continuing construction in an effective and safe manner. The utilization of NDT can help in determining the uniformity of strength in an existing slab deck and may also be utilized to determine the in-situ strength, which may result in fewer cores required when determining the strength of an existing slab. Some of the nondestructive tests that are used to determine the strength of concrete at an early age are: the maturity concept, pullout and ultrasonic test. The use of more than one testing method can be beneficial in attaining higher quality control standards. In this task the Windsor Pin test (ASTM C 803M) and the Schmidt rebound hammer test (ASTM C 805) were



(a)



(b)

Fig. 2 Test setup for tension specimens (a) TC specimens, (b) TE specimens.

evaluated. In order to meet the scope of the proposed task five concrete mixes with various mix composition were investigated. The tests were conducted at various ages of 1, 3, 7, and 28 days. The mixes were designed to have strength variation between 10-80 MPa. Also, 100 mm Cubes and 150 × 300 mm^2 cylinders were utilized.

Tests were performed on five concrete mixes using Type I Portland Cement. Mixes 1 was used as the reference mix. Mixes 2-5 contained a combination of micro silica, metakaoline and ground granulated blast furnace slag (GGBS). The mixes contained coarse aggregate with maximum nominal size of 20 mm. Rheobuild and Glenium admixtures were utilized in the mixes. The Glenuim high water reducing admixture was utilized in mix five that was expected to produce concrete with compressive strength of 80 MPa. The w/cm ratio for the five mixes was varied between 0.32-0.38. Tests were carried out on the five concrete mixes - Mix 1-5. A total of sixty concrete cylinders (150 × 300 mm^2) and 120 cubes (100 × 100 × 100 mm^3) were cast utilizing ready mix batching. Half of the cylinders and cubes were left to cure in the site with temperature variation between 31-43 $^{\circ}$C, while the other half were wet cured in the laboratory according to ASTM C 39 specifications. A total of five concrete retaining walls were also constructed on site. Nondestructive tests were performed on the concrete walls as well as cylinders and cubes. Three cylinders and three cubes cured under laboratory were tested at different ages of 1, 3, 7 and 28 days and similar number of cylinders and cubes were tested at field conditions. Tests were performed utilizing the Windsor pin and the Schmidt rebound hammer nondestructive tests. Ten readings were taken on each cylinder with each device. The cylinders and cubes were then capped and tested for their compressive strength Fig. 3.The following conclusions can be made from testing cubes, cylinders, and walls under laboratory and field conditions: (1) Compressive strength at 1 day of cubes and cylinders cured at site

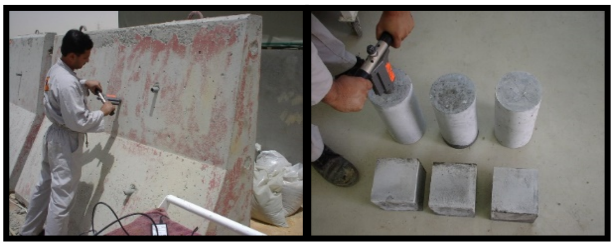


Fig. 3 Test setup for beams and walls.

condition have higher strength than specimens cured at lab conditions. The opposite trend was obtained at 28 days; (2) The overall ratio between cube and cylinder strength for laboratory and field conditions averaged 1.16; (3) Linear and exponential relationship between compressive strength and the pin penetration as well as the compressive strength and rebound number were established under laboratory and field curing conditions; (4) The graphs in this study provided a good linear-relationship between compressive strength and the pin penetration as well as the compressive strength and rebound number. The coefficient of variation was small indicating that both methods are reliable for the wide range of compressive strength between 10-80 MPa.

5.3 XTemperature Effect on Repair Deficient Reinforced Concrete Beams Using Fiber Reinforced Polymer (FRP) Materials

Recently, the use of FRP (Fiber reinforced polymers) is expanding in the application of repair, rehabilitation, and strengthening of RC (Reinforced concrete) structural elements. What makes FRP attractive is not only the high strength it has, but it is also considered a very light weight, and non-corrosive material, especially when it is compared to other conventional materials used for similar application (that is, repair, rehabilitation, and strengthening). The load carrying capacity of FRP-strengthened structures depends primarily on the effectiveness of the bond between FRP sheets and concrete surface. This bond is influenced by a number of factors such as type of FRP sheets, type of resin, compressive strength of concrete, workmanship, and temperature level. While the effect of many of these factors have been studied in the literature, there is not much information on the influence of temperature on bond strength. Therefore, this research examines FRP-repaired beams in high temperature weather to investigate such an effect to the strength of the repaired-structure comparing it to room temperature case. Few research papers have been found in the literature discussing the effect of temperature on FRP strengthened/repaired structure. The common conclusion can be abstracted is that the high temperature has a negative effect on the bond strength. However, the guidelines recommends more investigation on FRP contribution in repaired/ strengthened structure elements at high temperature Fig. 4: shows the beam setup inside the lab and outside exposed to hot weather conditions. Therefore, this research is expected to expand the knowledge in this field. Figs 5, 6 and Table 1 show the results of the first phase of the Instrumentation Stage.

Current research can be summarized in following points: (1) Repair or strengthening of damaged or virgin RC beams using EB FRP is much effective technology comparing to the traditional methods. (2) The behavior of this new technology wasn't affected by high temperature {around 60ºC} which was even

(a) (b)

Fig. 4 Stag (a) inside and (b) outside.

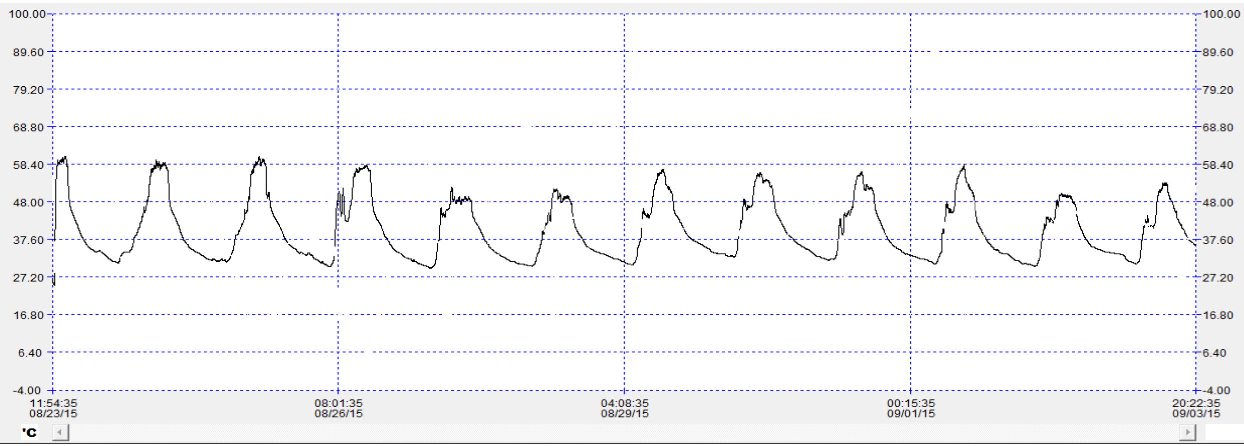


Fig. 5 Temperature °C.

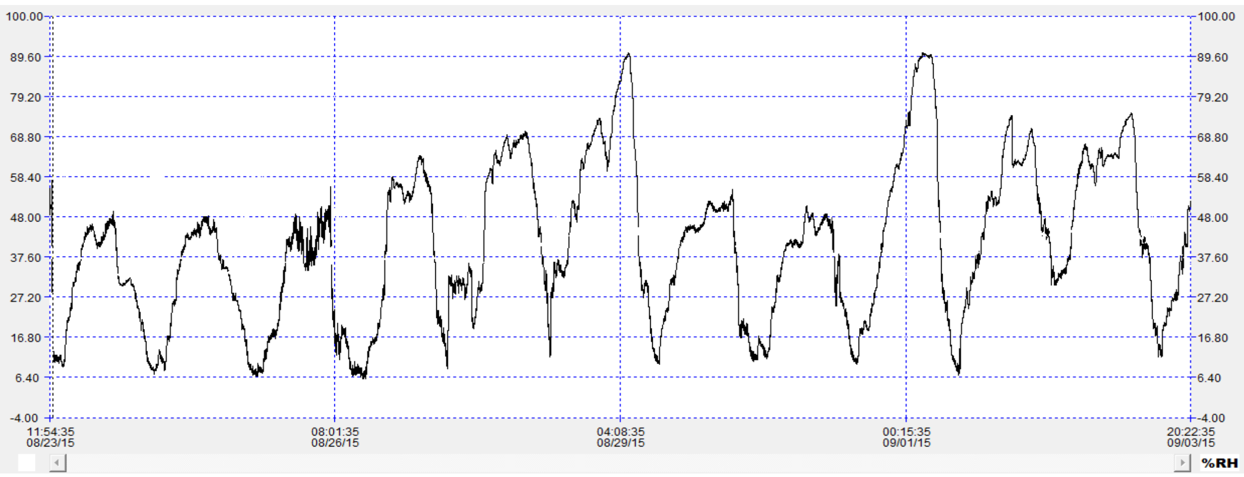


Fig. 6 Humidity %.

Table 1 Results of Phase 1 of the beam tests.

Beam type	Original shear capacity (KN)	Repaired shear capacity (KN)	Shear gain by FRP (KN)	Predicted shear gain by FRP (KN)	
				ACI (2008)	Fib (2001)
RB-inside-a	123	244	121	107	96
RB-inside-b	140	248	108	107	96
RB-outside-a	133	258	125	104	94
RB-outside-b	157	234	77	104	94

equal to its {Tg} temperature. (3) Our results shows that Repair of deficient structures using EB FRP will be a reliable method for Gulf countries particularly UAE that is known for its hot weather. (4) Further studies need to be carried on FRP above the Tg temperature for samples.

Final Observations can be summarized as High ambient temperature, low relative humidity, salt contaminated dust, sea water and underground salts in the region makes it of uttermost importance to make sure that all admixtures, additives and repair materials used be tested and evaluated for the severe ambient of the region. Guidelines, specifications and codes that don’t take the extreme environment conditions in the Gulf region into consideration will render structures that are non-durable and non-sustainable.

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