PREPACKAGED POLYMER – MODIFIED MORTAR PROVES EFFECTIVE CONSTRUCTION MATERIAL – FIELD AND LABORATORY OBSERVATIONS

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ABSTRACT

Hi-Bond – prepackaged polymer - modified mortar described in this paper is a revolutionary, multifunctional, high-tech, high performance, sustainable, durability improving group of construction materials with a high cost - benefit ratio. Hi-Bond has been developed by Dadabhoy Construction Technologies (Pvt) Ltd., (DCTL), Karachi, after extensive studies and research both locally and abroad. It can be used in floorings and pavings, integral waterproofings, adhesive applications, protective and decorative coatings, repairs, renovation, rehabilitation, anticorrosive linings, deck coverings, durability and efficiency improvement of canal linings and other hydraulic structures. Hi-Bond has been applied in various projects of national importance with great success for their repairs, renovation and rehabilitation and has also been tested and evaluated at various laboratories with highly encouraging results. Some examples include : (i) earthquake damaged bridge at Lora Nallah on Brewery Road, Quetta, (ii) fire damaged building of the daily Business Recorder House, Karachi, (iii) 200 - year old main dome of the tomb of Hazrat Shah Abdul Latif Bhitai, Bhitshah, Hyderabad, (iv) RCC shell roofs of Mehtab Biscuit and Wafers Factory, Sahiwal, (v) repair of newly built concrete floor on structural slab in a factory building at Karachi, (vi) Mohatta Palace, Clifton, Karachi, (vii) swimming pool at Okara Cantt, and (viii) numerous leaking basements, underground and overhead water reservoirs at and around Karachi including those of new vegetable market on super highway. Building Research Station, Government of the Punjab, Lahore also recommended the use of Hi-Bond in the applications mentioned above after testing and evaluation. The product was found easy in application and offered numerous technical and economical advantages, over conventional products, in variety of applications. It is important to note that shortly after the repairs and renovation of the building of the daily Business Record House as mentioned above, Karachi was jolted with an heavy earthquake, at approximately 7.1 rector scale, in 2001, however, the repairs successfully withstood the seismic forces with no signs of any deterioration showing excellent performance of Hi-Bond. In studies conducted at Department of Civil Engineering, Mehran University, concerning the repair capability of paste made by Hi-Bond (Universal) and paste made by normal cement, it has been established that Hi-Bond (Universal) paste - repaired concrete beams and cylinders have taken such loads which are quite comparable with original load of virgin specimens showing more bonding adhesion than normal cement paste and thus establishing the improved repair capability of Hi-Bond (Universal). Moreover, while testing the water tightening capability of various materials, Hi-Bond (Universal) was found to be best. It is

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believed that use of Hi-Bond in the country including projects in the upcountry areas will be a technical gift to Pakistan.

INTRODUCTION AND BACKGROUND OF DEVELOPMENT OF HI-BOND

Hi-Bond is a revolutionary, multifunctional, high-tech, high performance, sustainable, durability improving group of construction materials for 21st century and belongs to the category of "Concrete – Polymer Composites" (1). Hi-Bond fulfills the following six principles proposed for durable constructions (2). These include minimize resource consumption (Conserve), maximize resource reuse (Reuse), use renewable or recyclable resources (Renew/Recycle), protect the natural environment (Protect Nature), create a healthy non toxic environment (Non Toxicity), pursue quality in creating the built environment (Quality). Hi–Bond is extremely essential for durable constructions and is a proportionate mixture of cement, sand, various advanced polymers, superplasticizer, shrinkage reducing and water repelling agents. Only water is required to be added to Hi-Bond before use and hence it is ready-to-use construction material. Hi-Bond can be used according to need and circumstances in almost every stage of construction, i.e. from foundations to finishing and decoration, in various forms. Extensive studies and research have led to attain the capability to develop such ready-to-use advanced multifunctional construction materials. It should be borne in mind that for any strong and durable construction, just inorganic binders like cement, lime or gypsum are not sufficient. This is because all these materials are inorganic in nature. Although they do posses the required compressive strength, yet, they have lesser adhesion and hardly any ductility. Nor they have that tortuous system of pores which is very essential for durable constructions. Owing to these deficiencies, repairs using only above mentioned inorganic binders are never durable. Inorganic binders also lack water – proofing qualities. Furthermore, these materials alone can not provide sufficient defense against abnormal or hostile weather conditions including freezing and thawing and exposure to water or earth in case of water retaining structures known as environmental engineering concrete structures (EECS) as per ACI terminology.

Old structures of ancient times, i.e. "Structures of Pre - Cement Induction Period", which still retain their original beauty were constructed not only with lime / gypsum and stone but also contained elasticity and adhesion improving naturally occurring ingredients, i.e. rice extract, pulses, animal blood, egg, albumen, etc., resembling those present in Hi-Bond. In fact, there is a long list of such ductility and adhesion improving ingredients which were used in old times in constructions depending on their local availability. Because it was not a technological age, the process of combining these ingredients with inorganic building materials was rather lengthy and time consuming.

In the present era, cement is the basic construction material and is used all over the world. It is used in the form of mortar (cement + sand + water) and concrete (cement + sand + stone + water). Before the details of Hi–Bond are elaborated, deficiencies of mortar and concrete must be considered which necessitates the use of Hi-Bond alone in pure form or Hi–Bond in combination with mortar mix or concrete mix.

Both mortar and concrete are prepared with some suitable mix proportions for a particular work. While designing mortar and concrete mixes, mainly their compressive strength is considered and such mortar and concrete are generally considered better which have more compressive strength. Different standards are available for guidance in this regard. Nowadays, durability of mortar and concrete is also linked to their compressive strength. This means that mortar and concrete which posses better compressive strength should also be more durable. But pore characteristics of the system like size of pores, their distribution and inter–connectivity is ignored in mix design considerations. These pores are created in mortar and concrete due to evaporation of water because of a change in the temperature or due to air entertainment and are not apparently visible. To observe them special methods and equipments are now available. These pores have marked effects on the durability of mortar and concrete. A few large inter - connected pores may prove more dangerous than numerous separated or discrete small pores. Such large inter - connected pores may provide a direct or untortuous path in mortar and concrete through which ingress of deteriorating agents such as chloride (Cl^-) ions, carbon dioxide (CO_2) gas, etc., is easily possible without any resistance. These deteriorating agents either directly destroy the mortar or concrete by neutralizing them or corrode the existing reinforcing bars of the system. Corrosion of reinforcing bars then eventually leads to spalling and deterioration of concrete. Due to this reason early deterioration of concrete has also been reported (3).

Hence, the system of above mentioned pores plays an important role in determining the durability of mortar and concrete. It has been established from studies and research that ever mounting aerial and land pollution affects the structures as much as it does to human health and structures begin to show signs of deterioration or disintegration much earlier than their designed life based on strength consideration alone. Therefore, durability of mortar and concrete can not solely be attached to only compressive strength. Hence, other durability - related factors must be taken into account while designing the structures. Nowadays, durable and long-lasting mortar or concrete is the one which is prepared using minimum possible quantity of water yet having the required slump, has a required compressive strength, is dense and has a tortuous system of separated small pores. For effective repair and rehabilitation works, mortar and concrete must also have better adhesion and elasticity in addition.

CHARACTERISTICS AND PRODUCT DETAILS OF HI–BOND ALONGWITH FIELD APPLICATIONS AND LABORATORY OBSERVATIONS

Hi-Bond is one such very high quality, high performance, workability and durability improving sustainable construction material and possess all the above mentioned characteristics required for durable and long–lasting construction. A monolithic effective plastic lining system of polymer films, which is automatically developed in Hi-Bond upon addition of water and after proper curing, is responsible for its improved behaviour.

Table given below shows the comparison of Hi–Bond (Universal) with ordinary mortar, whereas, Figs. 1&2 are the electron micrographs of unmodified (Ordinary) mortar and Hi–Bond (Universal) respectively (4).

COMPARISON OF HI–BOND (UNIVERSAL) WITH ORDINARY MORTARS

a. Fresh Mortar Properties

S.No.	Property	Hi–Bond (Universal)	Ordinary Mortary
01.	Unit Weight (kg/1)	1.9	2.0
02.	Air Content (%)	8.2	6.1
03.	Water Retention (%)	96.6	70

b. Hardened Mortar Properties

S.No.	Property	Hi–Bond (Universal)	Ordinary Mortary
01.	Total Pore Volume ($X10^{-2}$ cm^3/g)	10.3366	11.2531
02.	28–day Compressive Strength (kgf/cm^2)	320	234
03.	28–day Flexural Strength (kgf/cm^2)	130	74
04.	28–day Tensile Strength (kgf/cm^2)	47	24
05.	Max. Deflection ($X10^{-1}$ mm)	1.0	0.42
06.	Max. Extreme Tensile Fiber Strain ($X10^{-6}$)	1231	385
07.	Max. Tensile Strain ($X10^{-6}$)	380	82
08.	Flexural Modulus of Elasticity ($X10^4$ kgf/cm^2)	6.31	7.36
09.	Tensile Modulus of Elasticity ($X10^5$ kgf/cm^2)	2.27	2.63
10.	Crack Coefficient ($X10^{-2}$ cm^2/kg)	0.020	0.037
11.	Adhesion in Tension (kgf/cm^2)	22	5
12.	Water Absorption (%)	9.3	12.2
13.	Water Permeation (g)	6	66
14.	Freeze–Thaw Durability Factor	72	10
15.	91–day Carbonation Depth (mm)	10	21
16.	Index of Resistance to rate of Diffusion of CO_2	2.43×10^{-4} $\sqrt{t} + 0.15$ ($\gamma = 0.99$)	5.57×10^{-4} $\sqrt{t} + 0.53$ ($\gamma = 0.99$)
17.	91–day Chloride Ion Penetration Depth (mm)	10.5	22.5
18.	Apparent Chloride Ion Diffusion Coefficient ($X10^{-9}$ cm^2/s) i.e. Index of Resistance to Cl^- ion Diffusion	0.2	13.2

As apparent from the above table and Fig.1, unmodified mortar is of poor quality because of the absence of polymer films. Whereas, as apparent from the above table and Fig.2 (a-e), Hi-Bond (Universal), in opposition to unmodified mortar, shows greatly improved mechanical and durability characteristics because of the presence of polymer films.

Therefore, an improved mortar or concrete can be prepared by using Hi-Bond group of materials in pure form or by using it as an admixture in a ratio of 3 to 10 percent to the weight of cement in a mix. Addition of upto 10 percent Hi-Bond (Universal) in a cement mix may enhance its compressive strength by 25 percent because of the resulting low water - cement ratio. General characteristics of polymer – modified mortars and concretes can be found and compared elsewhere (7,8,9). Different usages of Hi-Bond are enumerated below:–

Application	Location of Work
Floorings & Pavings	Floors for houses warehouses, schools, hospitals, offices, shops, toilets, passages, stairs, gymnasium, factory, garages, railway platforms, roads, airport runways, etc.
Integral Water Proofings	Concrete roof – decks, mortar walls, concrete blocks walls, water tanks, swimming pools, septic tanks, silos, brick canal lining, etc.
Adhesives	Tile adhesive, adhesives for floorings, walling materials and heat - insulating materials, adhesives for jointing new cement concrete or mortar to old cement concrete or mortar, etc.
Decorative Coatings (including surface preparing materials)	Wall coatings, lightweight aggregate coating materials, cement filling compounds and self–levelling cements for surface preparation.
Repairing Materials	Grouts for repairing cracks and delaminations of concrete structures, repair of siphons and canal falls and water outlets, patching materials for damaged concrete structures, protective coatings for corroded reinforcing bars, etc.
Anticorrosive Linings	Effluent drains, chemical or machinery plant floors, grouts for acid – proof tiles, floors for chemical laboratories and pharmaceutical warehouses, septic tanks, hot spring baths, etc.
Deck Covering	Internal and external ship - decks, bridge decks, foot bridge decks, train floors, etc.
Admixture to Mortar and Concrete	For improving the mechanical and durability characteristics of mortar and concrete including its use in canal linings and other EECS

Hi–Bond is very easy to use and is available in various forms for various applications. It is applied like any common mortar or concrete. Curing period is much less than that of ordinary mortar or concrete when used in pure form. Moreover, comparatively lesser quantity of Hi-Bond is used in comparison to ordinary mortar and concrete because thickness of the section can be reduced owing to its higher mechanical characteristics. Presently Hi-Bond group of materials consist of the following Products:–

1. Hi-Bond (Universal), 2. Hi-Bond (Tile Adhesive), 3. Hi-Bond (Tile Grouts),

4. Hi-Bond (Coloured Plaster and Decorative Coatings).

Rizwan and Kafeel (10) have also worked extensively on the use of other polymers in concrete and these appear to be inferior in performance when compared with Hi-Bond.

Since its launching in 1997, Hi-Bond has not only saved millions of rupees on repairs, renovation and rehabilitation works on the projects of national importance on one hand but has also preserved the national heritage (11, 12). Following is the summary of the jobs done on some of the projects using Hi-Bond :-

1. Rehabilitation of Earthquake Damaged Bridge at Lora Nallah, Brewary Road, Quetta

Piles on the above bridge were cracked due to an earthquake. These piles were restrengthened by filling the cracks with the pure Hi-Bond mix. Afterwards, piles were cladded with 8 inch thick Reinforced Cement Concrete (RCC) using 10% Hi-Bond (Universal) as an admixture i.e. 10% Hi-Bond (Universal) to the weight of cement in the mix. Hi-Bond (Universal) bond coats were also applied before each application to ensure better adhesion to old surface. Results of cladding were excellent. The resulting surface was extremely compact and strong. The test cubes of concrete mix using Hi-Bond (Universal) as a 10% admixture showed 25% increase in the compressive strength of concrete at a much lower water – cement ratio. Hi-Bond (Universal) thus proved itself as users friendly requiring minimum skilled labour and highly economical among similar group of materials particularly epoxies, etc. (5).

2. Repairs and Renovation of Fire - Damaged Building of the daily Business Recorder House, Karachi.

The building of Business Recorder House, Karachi suffered heavy damage due to fire in the year 2000. During the repairs, renovation and rehabilitation works, re-strengthening of cracked columns was done using Hi-Bond. Firstly Hi-Bond was applied as bond coat and then cladding (jacketing) of the columns was done with 6" thick RCC concrete using 10% Hi-Bond as admixture.

The result of cladding was excellent. The test cubes of concrete mix with Hi-Bond additive gave 25% increase in the strength of concrete. After repairs and renovation of building, Karachi was jolted with an heavy earthquake in the year 2001, however, the repairs successfully withstood the seismic forces with no signs of any deterioration showing excellent performance of Hi-Bond (13). In the above jobs Hi-Bond proved to be user friendly, requiring minimum skilled labour and highly economical among similar group of material particularly epoxies.

3. Repairs and Renovation of the Main Dome at the Tomb of Hazrat Shah Abdul Latif Bhitai, Bhit Shah, District Hyderabad, Sindh.

The above dome was a 200 year old masonry structure consisting of 3 feet wide walls, 25 feet diameter brick masonry set in lime mortar and 16 feet in height. The dome showed extensive cracking in the outer surface probably due to percolating of rain water inside the walls. Repairs and

renovation using ordinary cement mixes were almost impossible due to lesser adhesion and elasticity of material. Approximate cost for a new replacement was about Rs. 8,000,000/- (Rupees eighty lakh only). To save the costs and heritage, it was decided to repair and renovate the dome with Hi-Bond because of its higher adhesion, elasticity and other mechanical and durability characteristics. Outer surface rendering of the dome was removed. Masonry joints were washed properly. Surface was primed using prime coat made with Hi-Bond (Universal). Cement plaster using 7 to 10% Hi-Bond (Universal) as an admixture i.e. 7 to 10% Hi-Bond (Universal) to the weight of cement in the mix, was applied in two coats. Afterwards, 1/8 inch thick final coat of Hi-Bond (White Colour) in pure form was applied to give a permanent white coloured water-proof surface. In this way, the whole project was successfully completed in just Rs. 310,000/- (Rupees three lakh and ten thousands only), thereby saving millions of rupees. Hi-Bond (Universal) was therefore, proved to be simple to apply, users friendly highly economical and cost effective among similar group of materials (11).

4. Repairs and Water-Proofing of R.C.C. Shell Roofs of Mehtab Biscuit and Wafers Factory, Sahiwal.

The conventional bituminous treatment over shell roofs failed to stop water leakages through pour joints. In addition, various other hair - cracks also developed in the roofs. After proper surface preparation, a combined treatment using Hi-Bond and bitumen emulsion was given. A bond coat of Hi-Bond (Tile Adhesive) was applied. Afterwards, cracks were filled and surface was covered with $1:1^{1}/_{2}$ cement – sand mortar with 10% Hi-Bond (Universal) as an admixture. Damp curing was done for 72 hours using polyester cloth. Finally, the surface was covered with non – woven bitumen emulsion - impregnated polyester fabric over two coats of bitumen emulsion. After more than a year, the repairs and water-proofing is performing well without any complaints (14).

5. Repairs of Newly-Built Concrete Floor on Structural Slab in a Factory Building, Karachi.

A newly laid 1:2:4-3" thick floor at a local factory at Karachi could not offer desired prevention from abrasion due to rough usage. Hi-Bond was used to overcome this problem by resurfacing the floor in February, 2000.

A bond coat of Hi-Bond (Universal) was first applied on the existing floor and then 1" thick new floor with 4% Hi-Bond (Universal) as an admixture was laid in panels. The result was a very tough finishing surface, performing well till date (15).

6. Repairs and Renovation of Mohatta Palace, Clifton, Karachi.

Mohatta Palace, once a home to Mohtarma Fatima Jinnah - the Quaid's youngest and dearest sister, is a historical building and an architectural heritage at Clifton Karachi. Its successful repair and renovation was done using Hi-Bond (coloured plasters and grouts) (12).

7. Repairs, Renovation and Water-proofing of Swimming Pool at Okara Cantt.

A cement concrete swimming pool measuring 75' x 30' with a maximum depth of 11' – 0" showed vertical cracks un-eveness in walls, cracks and pits in floors. After proper surface preparation, repairs of cracks and pits were done using 10% Hi-Bond (Universal), to the cement, in 1:3 cement sand mortar after applying Hi-Bond (Tile Adhesive) as bond coat in October, 2001. Afterwards, ceramic tiles were fixed using Hi-Bond (Tile Adhesive) and Grouting of the above tiles was done using Hi-Bond (Tile Grout).

The use of Hi-Bond had turned an un-serviceable, abandoned swimming pool to useable one with 100% retention of water. Pool performance is excellent with no complaints till date (16).

8. Repairs, Renovation and Water-proofing of Leaking Basements, Underground and Overhead Water Reservoirs.

Hi-Bond has been used quite successfully for various repairs and rehabilitation works and as internal water-proof lining of basements, underground and overhead water retaining structures. The repairs of spalled concrete used Hi-Bond (Universal) either in pure form or as an admixture in varying ratios, to mortar or concrete mixes. Such works also included two overhead water reservoirs of New Vegetable Market, Superhighway, Karachi, each with a 50,000 gallons water storage capacity. Heavy leakages were stopped in both the facilities from the base floor around the columns and all around the base floor adjoining area after treatment with Hi-Bond (Universal). Other examples where Hi-Bond (Universal) was used for waterproofing purposes include :-

i. Basement of the Forum, Clifton, Karachi.

ii. Basement car parking area of Sui Southern Gas Company Limited, Head Office, Near Hassan Square, Karachi.

iii. Underground concrete pits, for steel storage tanks, PSO petrol pump, Gharo, District Thatta.

iv. Ambulatory ward cable trench, Agha Khan Hospital, Karachi.

In addition, Hi-Bond was also used as water-proof under-lay for tile - flooring at British Deputy High Commission, Karachi (17).

9. Recommendations of Building Research Station (BRS), C&W Department, Government of the Punjab, Lahore, for the usage of Hi-Bond.

BRS after testing and evaluation, recommended the use of Hi-Bond as a multifunctional construction product with diverse applications as mentioned in the table given above (6).

10. Repairs, Renovation and Water Tightening of Structural Concrete Members, Mehran University of Engineering and Technology, Jamshoro.

Continuous research work on the performance of Hi-Bond (Universal) is being carried out at Mehran University of Engineering and Technology, Jamshoro with a systematic engineering approach. Plain concrete beams and concrete cylinders have been cast and tested in tension. After tests, these beams and cylinders are repaired with normal cement paste and Hi-Bond (Universal) paste with various configurations. Retest results have indicated that Hi-Bond repaired concrete beams and cylinders have taken a significant higher load, which is quite comparable with original load of virgin specimens. It is also evident from experimental observations that in normal repair method we do get a line at the joint of old and new concrete, that has been overcome while using the Hi-Bond (Universal) with more bonding adhesion than normal cement paste thus establishing the improved repair capability of Hi-Bond (Universal). This is attested by the observations of Rizwan etal (18, 19) where polymer - modified cementitious systems have been recommended for repairs of normal concrete structures.

More than 100 standard concrete cubes are tested while applying painting layers of different water tightening materials (i.e., normal cement paste, Pudlo and Hi-Bond (Universal). Results have shown that performance of Hi-Bond (Universal) is the best out of the all the materials tested in accordance with the results of Rizwan etal (18, 19) wherein polymer - modified cementitious

systems showed to have reduced water absorption in comparison to normal cementitious systems. Hence

Hi-Bond (Universal) can be applied to waterproof the canal linings (both brick and concrete) and other concrete structures in the form of paint to restrict the water seepage/leakage with a high cost – benefit ratio.

CONCLUSIONS

1. Hi-Bond has been applied in the field in various projects of national importance with great success having a high cost benefit ratio.
2. In the above projects, Hi-Bond was used for repairs, renovation, durability improvement, and water - proofing of concrete structures. Various laboratory - scale testings also confirm the above behaviour of Hi-Bond which is observed from field applications.
3. Repair capability of Hi-Bond (Universal) is highly improved in comparison to ordinary (normal) cementitious systems. Hi-Bond (Universal) paste - repaired concrete beams and cylinders have taken such loads which are quite comparable with original load of virgin specimens showing more bonding adhesion of Hi-Bond (Universal) than normal cement paste.
4. Water - proofing capability of Hi-Bond (Universal) was also found best among various materials used for this purpose.
5. Hi-Bond is recommended for use in floorings and pavings, integral water proofings, adhesive applications, protective and decorative coatings, repairs and renovations, anticorrosive linings, deck coverings and durability/efficiency improvement of canal linings and other hydraulic structures.

REFERENCES

1. Ohama, Y. (2000) Recent Development of Sustainable Concrete - Polymer Composites in Japan. Proceedings of the International Workshop on Concrete Repair at the 4th Southern African Conference on Polymers in Concrete (ed. Deon Kruger), Rand Afrikaans University, Johannesburg, South Africa, pp. 1 - 14.
2. Kibert, C. J. (1994) Establishing Principles and a Model for Sustainable Construction, in Sustainable Construction, Proceedings of the First International Conference of CIB TG 16(ed. C. J. Kibert), University of Florida, Gainesville, Florida, pp. 3 - 12.
3. Qazweeni, J. A., and Daoud, O. K. (1991) Concrete Deterioration in a 20 - year Old Structure in Kuwait. Cement and Concrete Research, V.21, pp. 1155 - 1164.
4. Afridi, M. U. K. (1992) Effects of Powdered and Aqueous Cement Modifiers on the Properties of Mortars. Ph. D. Thesis, Institute of Chemistry, University of the Punjab, Lahore, Pakistan.
5. Loya A., (1998) Certification dated December 29, 1998 regarding the use of Hi-Bond in Rehabilitation of Bridge against Earthquake Damage - Bridge over Lora Nallah on Brewary Road, Quetta, Loya Associates, Karachi.

6. Deputy Director. (1999) Certificate No. 24-R/416 dated 04.02.1999 regarding Testing of Hi-Bond, Building Research Station, Lahore.

7. ACI Committee 548, (1973) Polymers in Concrete, Publication SP-40, ACI Detroit, U.S.A.

8. Ohama, Y. (1984) Polymer - Modified Mortar and Concrete; Chapter 7 in Cement Admixtures Handbook (ed. V. S. Ramachandran), Noyes Publica-tions, Park Ridge, U.S.A., pp. 407 - 410.

9. Ohama, Y. (1995) Handbook of Polymer – Modified Concrete and Mortars : Properties and Process Technology, Noyes Publications, Park Ridge, U.S.A.

10. Rizwan, S.A., Hussain, H.A., and Ahmed, K., (2001) A Comparative Study of Modified Concrete, Proceedings of the 68th Annual Session of Pakistan Engineering Congress, Lahore, pp. 313 - 323.

11. Memon, J. I. (2001) Certificate No. TC/G-55/340, dated 15.03.2000 from Executive Engineer, Provincial Buildings Division No. II, Hyderabad regarding Repair and Renovation of Main Dome of the Tomb of Hazrat Shah Abdul Latif Bhitai, Bhit Shah, District Hyderabad, Sindh, using Hi-Bond.

12. Afridi, M.U.K. (2001) Hi-Bond - Hi-Tech, High - Performance, Ideal Construction Material for Repairs and Renovation, Techno World, V. 3&4, p. 3.

13. Ahmed, K., (2002) Certificate dated August 09, 2002 regarding the use of Hi-Bond - Polymer Modified Mortar in Rehabilitation of Fire - Damaged Building of Business Recorder House Karachi, Loya Associates, Karachi.

14. Ahmed, N., (2001) Certificate dated October 04, 2001, regarding Repair and Water - Proofing of Mehtab Biscuit & Wafers Factory, Sahiwal.

15. Essa, M. S., (2000) Certification No. LCP/EXP - CER/036 dated February 19, 2000 regarding use of Hi-Bond in Concrete Floor Repairs, Alliance Consultants (Pvt) Limited, Karachi.

16. Rehmani S., (2001) Certificate dated October 30, 2001 regarding Rehabilitation and Improvement of Swimming Pool, Okara Cantt using Dadabhoy's Hi-Bond Polymer - Modified Mortars, Project Officer, Okara Cantt.

17. Rasheed H., (2001) Certificate dated August 09, 2001 regarding the use of Hi-Bond in Repairs, Rehabilitation and Water-proofing of Leaking Basements, Underground and Overhead Water Reservoirs, Protection Technology, Karachi.

18. Rizwan, S.A., Ahmed, K., and Hameed, A., (2002) "Comparative Response of SBR Latex Modified Concrete", Proceedings of the International Conference - Sustainable Concerte Constrction, Dundee, Scotland, U.K., pp. ,161 - 170.

19. Rizwan, S.A., Hameed, A., and Ahmed, K., (2002) Latex Modified High Performance Concrete, Proceedings of the 6th International Symposium on Utilization of High Strength / High Performance Concrete, Leipzig, Germany, pp. 1313 - 1324.