CEMENT MORTAR IMPROVEMENT USING RUBBER LATEX AS AN ADDITIVE

By

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DECLARATION

I Bala Muhammad, hereby declare that:

- this thesis is a record of a research work, designed, carried out, recorded, analysed and presented by me;
- this thesis had not been presented in any institution or any previous publication for a higher degreee;
- the sources of information have been duly acknowledged by means of reference and quotations, therefrom have been distinguished by means of quotation marks or otherwise.

Bala Muhammad

August 1997.

CERTIFICATION

This thesis entitled "Cement Mortar Improvement Using Rubber Latex as an Additive" by Bala Muhammad meets the regulations governing the award of degree of Master of Science (Civil Engineering Structures) of Ahmadu Bello University, Zaria, Nigeria; and is approved for its contributions to knowledge and literacy presentation.

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DEDICATION

This thesis is dedicated to YOU

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ABSTRACT

This thesis presents the results obtained on the effectiveness of rubber-latex as a means of improving cement mortar performance.

Mortar cubes of the two principal mix-ratios 1:3 and 1:6 were prepared and cured in ordinary moist environment and in an aggressive environment (untreated A.B.U dam water) for control strength and that of the defective cubes respectively. Another set of the cement mortar cubes of both mixes, modified with the polymer rubber latex-were also cured in the aggressive media in order to determine the effectiveness of the latex as a means of improvement. The curing periods for all samples in both the ordinary and the aggressive media were 7, 21, 28 and 56 days.

A significant change in the compressive strength was observed between control identical cubes (cubes without an addition of polymer) which were immersed in the two curing media correspondingly. The 7 day control strength is 24.74N/mm^2 while that of the defective cubes falls to 18.06N/mm^2 (a reduction of 27.0%).

Similarly, the average variation in strength figures for the subsequent curing ages are 14.7%, 13.8%, and 24.5% (i.e. for 21, 28 and 56 days respectively).

The reductions in the strength figures between the compared sets were as a result of the deterioration effect of the aggressive water used.

The effect of the rubber latex is witnessed from the results of the modified cubes obtained. Taking ratio 1:3 mix with an addition of 1.5% latex, the corresponding modified cubes strength are 27.42N/mm^2, 29.43N/mm^2, 30.09N/mm^2, and 33.77N/mm^2. thereby depicting increase in strengths of 51.8%, 25.7%, 20.0% and 36.5% respectively. Much higher strength increase were observed from the cubes of the ration 1:6 mix.

The increases in the strength values between the non modified and the modified cubes were as a results of the protection qualities of the modified agent.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL

The term 'Mortar' is used to denote a mixture of fine aggregate and some binding agent, used as a jointing or as a surfacing material. If sand is used as the fine aggregate and cement as the binding agent, the mortar is then known as 'cement mortar'.

Cement mortar has been the principal material used for screeding, plastering, bedding for making joints between bricks, blocks and stones in the construction industry. It is also used in the construction of piers, walling below and above damp proof level and chimney stacks. Other important uses of the cement mortar include; the application of its modified form either to achieve certain requirements like water-proofing and fire resisting qualities or as the most common means of repair system when leakage or corrosion damages are perceived. Not only that, `concrete' itself denote a mixture of fine aggregate, coarse aggregate and some binding agent-thus, broadly, a combination of mortar and coarse aggregate.

Typical cement mortar mixes (by volume) are one part of sand to three parts of cement (1:3). This is suitable for exposed conditions and one part cement to six parts sand (1:6); suitable for most conditions with the exception of severe exposure.

Many factors affect the quality of cement mortar. These are the type of cement, source and grading of aggregate, quality and amount of mixing water, proportion of materials, workmanship and method of curing adopted.

Cement mortar is attacked at least to some extent by a variety of chemicals coming into contact with it. Acids and sulphates do the most damage. Hydrochloric acid is the major cause of deterioration when compared with nitric and sulphuric acids and its source may either be from the components of the mix (e.g accelerators like $CaCl_2$) or from the service environment of the structure (expose to sea water, de-icing salts e.t.c). The deterioration mechanism is well known as the initiation of corrosion, its progress with the formation of expanding corrosion products leading to, eventually, the formation of cracks that leave the way open for further attack.

1.2 STATEMENT OF THE PROBLEM

Acids in significant concentrations are encountered in special applications such as cider and sewage. Whereas sulphates occur in dangerous concentration in many soils in most part of the world. Sulphates in solution react with the constituents of the hardened cement paste. Sodium sulphate attack the tricalcium aluminate ($3CaO.\ Al_2O_3$) hydrate to produce sulphoaluminate and the reaction is accompanied by a considerable increase in volume which initiates disintegration. Sea-water as an aggressive environment too, has an adverse effect on the cement mortar when in contact with it. So also dam-water, lake-water and open running gutters do attack cement structures to such a degree corresponding to the concentration of the harmful substances present in the medium concerned. These media consist of harmful substances such as sodium sulphate, calcium sulphate, ammonium sulphate, ammonium chloride, potassium nitrate, sodium nitrate, sulphuric acid, hydrochloric acid and nitric acid: which are all considered highly aggressive to the cement structures. The effect of these harmful compounds on the cement weaken its ability to act as a good binding agent or causes loss in strength. The effects are attributed to the reactions taking place between the aggressive compounds and the cement matrix. For example sulphate corrosion is primarily due to the reaction taking place between salts and tricalcium illuminate content of the cement. Another typical example is that of calcium chloride hydrate which normally reacts with the tricalcium illuminate to form calcium chloroaluminate hydrate which is responsible for the softening of bonds between the inert particles and the binding medium.

1.3 JUSTIFICATION FOR THE STUDY

Since these aggressive chemicals can not be completely eliminated from the constructional or service environment it becomes logical enough to find a means of protecting the cement structures against the persistent attack.

The progress made in investigation, measures of protection and repair techniques of hydraulic cement structures has rapidly increased during the last decade and will continue to do so as the construction industry learns from past and present mistakes. Attempts made in protecting cement materials toward the ingress of aggressive agents include the employment of high quality concrete, surface coatings, catholic protection, polymer substances, hydrophobizing agents and the addition of chemicals inhibiting corrosion.

Surface coating whilst playing a vital role in protecting surfaces against external attack have not had sufficient field study which will take into account the severe exposure in many parts of the world, especially in the tropics. Chemicals inhibiting corrosion may also be added to the cement materials but the efficiency of these may be doubtful in a chloride contaminated environment.

1.4 THE ADDITIVE

Polymer is a common denominator for many of the protective measures of both concrete and mortar in an aggressive environment. Polymers are substances that exhibit the behaviour of liquids derived from amorphous solids rather than crystalline ones. Liquids derived from crystals consist of small raft of atoms arranged in the crystal structure, but the bonding is not strong enough for crystallites to link together and form a rigid mass. They are in continuous relative movement and the atoms on their edges are constantly detaching themselves from one group and attaching themselves to another. But the number of groups and also their individual size remain approximately constant. On the other hand, liquids derived from amorphous solids are composed of large molecules-frequently long-chain molecules- which have gained sufficient thermal energy to overcome any linking tendency and to become flexible and mobile so that they will wrangle past each other under stress. However, rigidity is maintained by cross-linking and entanglement of rigid long-chain molecules, or is the result of an irregular but well cross-braced array of atoms. Their bulk strength is then dependent on physical entanglement. The larger and more complex the molecules, the greater are the opportunities for these forms of linkage. Thus, the effectiveness of the polymers is due to the functional monomers incorporated in its long-chain molecules. The existence of the strong cross-linking bonds between the chain of the functional monomers is capable of forming chemical bonds with the cement minerals and once it is formed the polymer-cement compound will be insensitive to moisture; ngth is then dependent on physical entanglement. The larger and more complex the molecules, the greater are the opportunities for these forms of linkage. Thus, the effectiveness of the polymers is due to the functional monomers incorporated in its long-chain molecules. The existence of the strong cross-linking bonds between the chain of the functional monomers is capable of forming chemical bonds with the cement minerals and once it is formed the polymer-cement compound will be insensitive to moisture; this action is achieved by the ability of the polymer minerals to fill up the voids usually present in the cement structures in addition to the good bond existing between the two substances (cement and polymer)

Earlier polymer used in the construction of structures as means of protection against aggressive agents (i.e acids sulphates, bases, hot brine, freeze, thraw and deminerialized water) include; resins, polyester and epoxy. But the later development employed the use of tarpolymer-vinyl accetate/vinyl chloride/ethylene, copolymer-venyl acetate/versatic ester (vedua), copolymer-styrene/butadiene/rubber e.t.c.

In this research, a typical polymer substance rubber latex is considered. Rubber latex is a thick whitish liquid substance produced by rubber tree, its chemical name is poly 1-4 isoprene[1]. When exposed to air, it loses its some of water content thereby becoming relatively hard. To avoid this it is collected and immediately conveyed for the laboratory by means of an air tight container. The latex has up to 90% water content[2]. The addition of the substance into the fresh cement mortar mix is by percentage weight of the dry-mix. A polymer cement mortar (PCM) is therefore, a cement mortar to which polymer is added so that the material will acquire the ability to resist chemical attack, and to improve such properties like water-proofing, resilience, adhesion e.t.c.

1.5 AIMS AND OBJECTIVES OF THE RESEARCH

The aims and objectives of this research are to evaluate the effectiveness of rubber latex used in various proportions, as a means of improving the properties of cement mortar.

1.6 LIMITATION

The research will be limited to compressive strength tests only as a major criterion for accessing the effectiveness of the rubber latex.

CHAPTER TWO

2.0 LITERATURE REVIEW

Research on polymer substance as a means of protecting cement materials against the ingress of harmful agents has been under way since the early 1950s by investigators in various countries. These researches were mostly conducted by individual investigators, research centers or undertaken as a joint effort between the two. Most of the investigations were necessitated as a result of several careful observations of dermages-caused by destructive agents-principally, on the cement materials. Damages were observed from several perspectives, among which are, those to the natural or initial qualities of the materials (Akpan, 1990) performance specifications, production procedures employed, field performance (Dhir, 1978 and Yasui, 1978) and more critically, chemical aggression (Akpan, 1992, Seki and Yasui 1978) during the service life of the products.

Large scale research on polymer impreginated concrete (PIC) was undertaken in 1966 as a joint effort between the Bureau of Reclamation and the Atomic Energy Commissions Brook haven National Laboratory (A.E.C, 1978). At the end of the research, the bacis procedure for the production of PIC elements were established. These include driying the concrete components to remove free moisture, placing the elements in vacuum to remove air pockets, immersing the elements in a liquid monomer under pressure to achieve saturation and finally polymerizetion of the monomer by heat or radiation. Upon close inspection PIC may be distingushed by the presence of polymer in air voids of the products. It was concluded by the research team that the beneficial effects of ploymer impregnation are largely a result of void and microfracture filling.

Justnes and Oye (1978) of the Cement and Concrete Research Institute Denigton-Norway in a research 'Protecting Concrete Against chloride Ingress', discovered that polymer substance effectively blocks chloride from entering cement material that has been modified by this substance. Similar discoveries were made by Bishara (1979) and Clear and Chollar (1978) in their research respectively. The latter used Styrene Butadienne as the modifier. According to Justens and Oye, the necessary dosage for adequate protection against chloride ingress is found to be dependent on the water-cement ratio and the content of the entrained air. A ten percent addition of the polymer has proven to be sufficient even at high air content and moderate water cement ratio (0.55). The results of the research also confirmed that some polymers partially remulsify when the precast cubes are immersed in water. One commercial available polymer containing copolymerized vinylchloride, has been proven to produce free chloride during hydrolysis in the alkaline interior of the mortar.

Silica fumes as an alternative to latex was also considered by Justnes and Oye (1978) The fumes were observed to have possessed protective qualities by blockage system (i.e by blocking the possible ingress of aggressive agents). The substance was introduced into both concrete and cement cubes for tests and the introductions were made by replacing some amount of cement with the fumes in the range of 1% to 10% by weight at a constant water cement ratio. It has been noted that the replacement of cement with 10% condensed silica fume incresed the mechanical strength considerably at a constant water cement ratio[0.55], the effect on the chloride penetration was less than it was with the latex. Thus, concluded that the protection offered by the latex has shown superiority over that provided by condensed silica fumes.

Humes, Melbourne (Humes 1978) Australia has developed and evaluated Polymer Precast Elements (PPE) containing not more than 5% polymer. The process includes compaction methods which can give a virtually void-free material. A major achievement of an absolute void-free condition is that of rendering the material self-protective against any possible harmful aggression. But in practice this is not easily achieved. However, observations revealed that materials with more pores are weaker and are therefore more liable to attack by aggression As such, efforts were aimed at obtaining materials with minimum pores possible. Humes, therefore, employed this advantage and that of the polymer to assess the suitability of the PPE in aggressive environments. The results of his investigations were successful, and since then,elements of this kind have been in use.

One major practical application of this type of elements is that of piping systems. Such pipes are used in the underground pipe field where portland cement concrete would be subjected to shortened life from attack by aggressive ground water, hydrogen sulphide or industrial waste. Initial strengths of this pipe are greater than portland cement concrete (that has not been modified by polymer) by up to a factor of 5.

Popovics (1978) in his research, conducted experiments on cement mortar concerning addition of water dispersible epoxy system and furfuryl alcahol with catalyst. He pointed out that a polymer modified cement is prepared by integrally mixing water solutions or emulsions of polymers of polymersable monomers with cement and aggregate. The water in the emulsion or solution hydrates the cement; the chemicals should form a polymer before or during the hydration of the cement and enter this structure of the cement paste.

Okada, Morita and Koyahag (1978) of Kyoto University, Japan working as a committee, in collaboration with twenty-four institutes and research laboratories investigated the validity of polymer-cement mortar. Among the polymers selected for the research are: acryties dispersion and vinyl emulsion. Properties such as flexural and compressive strengths, water absorption, water permeability, initial setting shrinkage, adhession, extensibility, abration, water retensions and resistance to chemical tests were all carried out. The results indicated that in general, mechanical and physical properties such as strength, absorption, permeability, e.t.c., are considerably affected by water/cement ratio. Consequently, water content is one of the most important items in the tests.

Surface coatings, whilst playing a vital role in protection against original failure of the new structures, or the on-going deterioration of the repaired structures have had insufficient field study to take into acount the severe exposures in many parts of the world. After careful investigation, Harwood (1978) of the United Kingdom pointed out that the choice and selection of the surface coating is most important, depending on the specific requirements of the structure. In other words the act of random selection of suface coatings chosen for initial cost or appearence considerations alone are very likely to result in early failure. Care is needed to consider precisely the individual requirements of the given structure, taking into account the local conditions of exposure. Harwood, further attributed the success of protection by serface coatings to the surface preparation carried-out prior to the application of the coats.

In fact, while considering surface coatings as a means of protection, servaral preceeding steps will have to be taken, and these are to be followed by the actual process. The figures below suggest these steps as outlined by Harwood.

THE REPAIR PROCESS STAGE I

Survey => Diagnosis => Assessment => Specifications + Documentation

Fig. 2(a)

THE REPAIR PROCESS STAGE II

Selection => Cleaning => Site Testing => Repair => Protective Coating => Site Supervision

Fig. 2(b)

It is a fact that, all concrete surfaces, whether new or weathered, will have weak cement laitance, oil grease or surface contamination deposits and if these are not removed, the coating will fail sooner or later.

Robinson, (1986) has indicated the significance of weathering on the performance of the coating. Weathering from ultra violet light, changes in humidity and temperature and these deteriorate the binder in the surface coating, thereby reducing the resistance to thermal stresses and a considerable reduction too in the thickness of the dry film coating. An indication of the resistance of the coating to water ingress or carbonation early in its exposure life, may therefore become quite misleading. The fast deterioration of the coating is evident even if the initial degree of the effectiveness is high .

Fattuhi (1978), University of Kuwait in his evaluation programme found that, an ethylene copolymer reduces carbonation rates by almost thirty five fold. Thus, in situations where there is the possiblity of a rise in humidity with consequent increase in condensation and a drop in temperature, a correctly formulated ethylene copolymer was found to be suitable as it will bridge cracks pro rata with its dry film thickness. Klopfer (1978), experimented on how to combat it rather than introducing a material to guard against it (the carbonation). Nevertheless, Fattuhi, discovered that the formulated ethylene copolymer will (in addition) provide good resistance to carbonation and a resistance to high water vapour transmission too.

CHAPTER THREE

3.0 EXPERIMENTAL PROCEDURE

3.1 MATERIALS

The materials used in this research are: cement, sand, water and rubber latex. These materials were all investigated for conformity with the standards and appropriate measures taken for incidentals where necessary.

3.1.1 CEMENT

Ordinary Portland Cement is used in this research, specifically, the OPC manufactured at Ashaka Cement Factory, Bauchi - Nigeria. Request was made from the latest supply so as to ensure freshness.

3.1.2 SAND

Sand (river - sand) is chosen to be used in this research. The sand was collected from river side and examined for conformity with the standard requirements. Finally, the sand obtained consisted of particles smaller than 5mm size and contained not more than 3% silt (i.e standard requirement for natural sand). This was achieved after conducting the necessary tests such as sieving (using No. 100 standard sieve - 0.142 mm) and weighing.

3.1.3 MIXING WATER

Tap water was used. A check was made so as to make sure that it is qualitative.

3.1.4 RUBBER LATEX

It is the natural rubber - tree latex, obtained from the rubber - tree plantation, Cross Rivers state, Nigeria (see section 1.4).

3.2 SPECIMEN PREPARATION AND TESTING

3.2.1 CLASSIFICATION

Principally, the cubes are of two categories (i) and (ii), category (i) consists of cubes without latex (i.e control specimen) while category (ii) is of those with an addition of rubber latex.

Category (i) is of two divisions (A) and (B); those cured in the ordinary medium (i.e normal cubes) and those cured in the aggressive medium (i.e affected cubes). Furthermore, there are two types of mortars; mortar of the ratio 1:3 and that of the ratio 1:6 cement and sand respectively.

The cubes of category (ii) are the polymer modified group. The modification is the addition of the rubber latex by percentage weight of the dry mix. Mortars containing 1%, 1.5%, etc of the rubber latex are prepared for the test.

3.2.1.1 NORMAL CUBES

The normal cubes are tested for the computation of the normal strength values. These are therefore the reference values for the evaluation of the degree of loss or gain in strength as might be the case with the affected and modified cubes.

3.2.1.2 AFFECTED CUBES

Affected cubes are normal cubes in composition but cured in an aggressive medium.

Although, affected cubes do not contain the modification agent, but they are still subjected to the aggressive medium. The purpose of which is to determine exactly, the possible degree of effect on the mortar cubes, due to the aggressiveness of the curing medium. The value of the degradation is obtained after comparing the affected cube's strength with the normal cube's strength.

3.2.1.3 MODIFIED CUBES

Cubes containing some specific amount of percentage latex (by weight of the dry mix) are the modified cubes. These are subjected to the aggressive environment as their curing medium. They are therefore the category II group, in the classification of the cubes earlier identified in this chapter, (see 3.2.1).

It has also been earlier mentioned that, the percentage latex added is by weight of the dry mix and that the percentage ranges from 1% to 3% with an increase of 0.5% from the initial percentage. The choice of this range is in connection with the anticipated amount of air pockets and microfracture voids in the solid mass of the mortar. It is believed that the most appropriate dosage of the rubber latex necessary for the most effective protection is that amount just sufficient enough to fill in the voids of the material, or rather an amount that will not cause any displacement of the inert particles of the mix.

The strength of the modified cubes are expected to make even (or more) the lost strengths indicated by the affected cubes: This will yield a positive result.

3.2.2 PREPARATION

The materials, namely cement, sand, latex and mixing water were all measured using standard weighing and measuring devices. The cement mortar mixer used in this research has a fixed bowl capacity of three cubes of size 70.6mm.

A water/cement ratio of 0.40 by weight is used. The rubber latex is also calculated and measured in a similar manner. But, the amount of water content present in the latex is noted and an equivalent quantity deducted from the mixing water. This is necessary so as to avoid an excess mixing water. The amount of water present in a unit volume of rubber latex is about 90% of the volume.

Dry mixing was carried out first, using a cement mortar mixer. The dry mixing is for 60 seconds and for further 120 seconds after the addition of the mixing water. However, in the case of category (II), the intended rubber latex to be added was measured, added to the mixing water and stirred thoroughly before adding the contents, to the already dry-mix cement mortar. This is necessary in order to achieve even spread of the polymer throughout the contents of the mix.

Over mixing in both cases (dry and wet conditions) is avoided as it causes a fall in the water met for hydration by breaking the inert particles into finer sand - leading to more surface area of the particles.

The freshly mixed mortar was placed into oiled steel moulds (cubic in shape), of size 70.6mm (2.78in) and vibrated for two minutes. A standard vibration machine was used for this purpose, which has a revolving capacity of 1200 - 1400 revolutions/minutes. After the vibrations, cubes were then allowed to remain in the moulds for 24 hours under covered conditions with non absorbent materials. At the end of the 24 hour stay in the moulds, removal, identification, weighing and immersion followed. The weighing exercise is for the purpose of assessing the amount of water absorbed.

3.2.3 IDENTIFICATION

Identification is necessary for the purpose of easy recognition. Since many units of similar sizes were involved in this research, simple and appropriate identification marks were chosen and used throughout the research work. An introduction to the identification system selected for the research is also necessary for the fact that much references were made in the present chapter and in the subsequent chapters.

If a sample is to be considered as that mix of a particular cement/sand ratio and a known percentage latex, then three cubes are made out of each sample. The letters 'X', 'Y' and 'Z' are therefore chosen for the first, second and third sample units respectively. See the Table below, 3.2.3(a). Where IM, is the identification mark.

Table 3.2.3(a)

Cube's No	Cube 1	Cube 2	Cube 3
IM; Letters	X	Y	X

However, many similar samples (i.e of the same cement/sand ratio and percentage latex) are prepared. One for each curing age. Therefore to differentiate a sample for one particular curing age from the other an upper prefix system to the above letters (X, Y, and Z) was considered. The curing ages are 7, 21, 28 and 56 days. These curing ages are presented by the numbers

01, 02, 03 and 04 correspondingly, as shown in Table 3.2.3(b). Where IM is the identification mark.

Table 3.2.3(b)

Curing Ages (in days)	7	21	28	56
IM; Number Prefix (upper)	01	02	03	04

Furthermore, if a sample is for a particular cement/sand ratio and percentage latex, then for the purpose of varying the percentage latex, the lower prefix system is employed. This is shown in the Table below 3.2.3(c). Where IM is the identification mark.

Table 3.2.3(c)

Percentage Latex (by weight)	0%	1%	1.5%	2%	2.5%	3%
IM; Number Prefix (lower)	00	01	02	03	04	05

It will be observed that the identification marks for 3.2.3(b) and 3.2.3(c) are the numbers occupying the second place of each prefix, while the first places were occupied by zeros. As such, to differentiate one mix from other (i.e to differentiate between the ratios 1:3 and 1:6), the zeros in the lower prefix are to be replaced by 1 for the ratio 1:3 and 2 for the ratio 1:6. See the Table below where NPL is Number Prefix - Lower.

Table 3.2.3(d)

Rating	1:3	1:6
IM; NPL	10	20

Similarly, the curing medium will be identified by the numbers replacing the zeros in the upper prefixes. The ordinary medium (i.e the tap water) will be presented as 1 and the aggressive water (i.e the dam water) will appear as 2. See Table 3.2.3(e).

Table 3.2.3(e)

Curing medium	Tap water	Dam water
IM; NPU	10	20

Following, is a Table (i.e 3.2.3f) representing all the cubes produced in this research. The Table also depicts all the major information as regards the requirements for the laboratory work.

Table 3.2.3(f)

CURING PERIOD (DAYS)

Percentage Latex	**7 Days**		**28 Days**		**28 Days**		**56 Days**	
	1:3	1:6	1:3	1:6	1:3	1:6	1:3	1:6
0%	A3	3	3	3	3	3	3	3
0%	3	3	3	3	3	3	3	3
1%	3	3	3	3	3	3	3	3
1.5%	3	3	3	B3	3	3	3	3
2%	3	3	3	3	3	3	3	3
2.5%	3	3	3	3	3	3	3	3
3%	3	3	3	3	3	3	C3	3

Some samples were selected from the Table and these were marked A, B and C. The aim is to identify them by the identification marks so as to serve as examples.

Table 3.2.3(g)

A	B	C
X^{01}_{10} Y^{01}_{10} Z^{01}_{10}	X^{22}_{22} Y^{22}_{22} Z^{22}_{22}	X^{24}_{15} Y^{24}_{15} Z^{24}_{15}

Generally, a cube is represented as shown below, and the inscription of the identification marks were carried out either after casting or before weighing. $C^{(CM)(CA)}_{(RM)(PL)}$

Where: CM => Curing Medium

CA => Curing Age

RM => Ratio of Mix

PL => Percentage Latex

C => Cube

3.2.4 WEIGHING

The weighing is carried out at the end of the 24 hours stay in the moulds and at the end of the curing period. The former gives the weight in the presence of air (only) in the voids, while the latter gives the weight of the former and that of the moisture (i.e. the air pockets are being taken up by the moisture).

The reason behind the bi-weighing is mainly to account for the amount of water absorbed. This will help in accessing whether or not, that, the effectiveness of the latex is affected by the amount of the aggressive moisture gaining entrance into the air voids and microfractures of the mortar.

A void free mortar will only require protective measures on its surface. But, as this is not easy to achieve and since the mortar will have voids, it is therefore believed that the more the voids (i.e the higher the void ratio) the more the aggressive agents will be in the mass of the mortar. This will lead to a greater attacking capacity with a consequent increasing degree of deterioration.

3.2.5 CURING

Curing is carried out in the laboratory and all the cubes were cured by the process of full immersion. The minimum curing age is 7 days and the maximum is 56 days, with intervals of 14, 7 and 28 days in between the two limits.

The reason for the choice of the lower limit as 7 days is attributed to the fact that mortar will normally acquire a relatively higher strength in a much lesser period than a concrete of similar size. However, the upper boundary limit is choosen due to a fact established in the previous research (Akpan 1992) i.e. if 'cement mortar is attacked by a highly concentrated aggressive agent for a prolonged period of time, (starting from the surface) the inert particles of the mortar will be washed off or rather the solid mass of the material may dissolve into granulated particles-with time'. The occurance of this will surely create a gap for comparative results. To avoid this in addition to the first factor, the dam-water is chosen as the aggressive medium and the maximum curing period limited to 56 days. Even with these precautions being taken, the unprotected cubes with longest curing age were observed to have suffered from the stated anticipated deterioration. The curing media are of two types, namely, normal or ordinary medium and aggressive or harmful medium. The ordinary one is of normal tap water, and it is used to cure cubes expected to give reference strength. The aggressive medium is the untreated ABU dam-water, its analysis have shown that the concentration of salts is as follows[1], Sodium 0.832, Potassium 0.431, Calcium 0.044, Magnesium 0.119, Chloride 1.593, Sulphate 0.153, Hardness 1.371 (all in g/mm^3). This serves as the medium in which both cubes (i.e with the protection substance and those without the protection substance) were cured.

The World Health Organisation (WHO) standards for water have considered certain characteristics of water as being excessive. These include chloride 0.6, hardness 0.5, sodium 1.0, magnesium 0.15, sulphate 0.4 (g/mm^3). From this it can be seen that the aggressive of the untreated water is more on the chloride contents.

3.2.6 TESTING

At the end of each curing period, three cubes of the same percentage latex and mix proportions were removed, weighed and air-dried for atleast 48 hours. These were then tested for compressive strength, by using a standard compressive strength machine. In order to ensure accurate results while crushing, the cubes were (normally) centrally placed into the machine and the rate of loading of the compressive machine was not more than $350KN/M^2$ (i.e. $0.35N/mm^2$). The average strength of the three cubes for each group is the strength value considered for that particular sample.

3.3.0 RESULTS

3.3.1 COMPRESSIVE STRENGTH

The results of all laboratory work, including experiments and tests were presented in this section. The experimental research work were all conducted under the laboratory conditions. Thus, the size and duration of the research work, the magnitude of the resulting figures, the necessary analysis of the results and the system of presentations unless where necessary - were all similar to the general mode or pattern of presentations of results realised from experiments made under the normal laboratory conditions. However, some of the result - figures were presented under appendix.

Table 3.3.1

COMPRESSIVE STRENGTH OF THE MORTAR CUBES

Mix Proportion	Percentage Addition of Latex (%)	Compressive 7 days	21 days	Strength (N/mm^2) 28 days	56 days	Average Strength (N/mm^2)
1:3	0% (Normal cubes)	24.74	27.43	29.00	32.77	28.49
	0% (Affected cubes)	78.06	23.41	25.08	24.74	22.82
	1%	26.75	28.75	29.43	32.10	29.26
	1.5%	27.42	29.43	30.09	33.77	30.18
	2%	22.74	26.08	28.09	22.10	24.75
	2.5%	19.06	22.74	23.74	27.62	23.43
	3%	13.04	16.39	20.06	23.74	18.31
1:6	0% (Normal cubes)	5.42	5.75	6.02	6.25	5.86
	0% (Affected cubes)	4.01	4.61	5.02	5.42	4.77
	1%	4.01	5.35	5.92	6.15	5.36
	1.5%	4.61	5.89	6.59	6.96	6.01
	2%	5.62	6.49	6.89	7.39	6.60
	2.5%	4.61	6.75	7.49	7.82	6.67
	3%	3.41	5.15	5.62	6.32	5.13

3.3.2 WATER CONTENT

The result of the water content of all the cubes were tabulated and presented in the table 3.3.2 and appendix II

Table 3.3.2

WATER CONTENT OF THE MORTAR CUBES

Mix Proportion	Percentage Addition of Latex (%)	Weight of Water 7 days	21 days	(Grammes) 28 days	56 days	Average Water Con. (Grammes)
1:3	0% (Normal cubes)	10.7	17.3	19.3	19.3	16.65
	0% (Affected cubes)	12.0	23.0	24.7	27.7	21.85
	1%	10.7	17.7	20.2	17.3	16.48
	1.5%	6.7	16.3	18.0	17.7	14.68
	2%	8.3	16.7	21.0	29.2	18.80
	2.5%	10.3	19.0	23.0	31.0	20.83
	3%	13.3	23.0	25.7	42.7	26.18
1:6	0% (Normal cubes)	37.7	58.8	70.7	85.7	63.23
	0% (Affected cubes)	44.7	74.0	78.7	84.7	70.53
	1%	36.3	56.0	70.0	83.2	61.38
	1.5%	35.7	53.3	70.0	78.2	59.30
	2%	33.7	46.7	69.0	76.7	56.53
	2.5%	30.3	60.0	65.0	74.0	50.58
	3%	33.3	64.3	65.0	75.3	59.48

CHAPTER FOUR

4.1 ANALYSIS AND DISCUSSION OF THE RESULTS

4.1.1 MORTAR STRENGTH (RATIO 1:3)

The compressive strength results of the normal cubes are 24.74 N/mm^2, 27.43N/mm^2, 29.00 N/mm^2, and 32.77N/mm^2, for the 7.81, 28 and 56 days respectively. The first three resulted to the usual fairly straight line graph of the initial curing days of the mortar specimen (see the graphs of the normal cube's strength, 'G-Normal' in figure 4.1.1(a)). However, the last three deficted percentage increases in strength - over that of the 7 day - of 10.9%, 17.2% and 32.5%. Considering the normal mortar strength development, this specimen is quite natural.

The change in the curing medium (i.e from normal to aggressive) causes a fall in the compressive strength of the cubes. The resulting figures for the four curing ages are 18.06N/mm^2, 23.41N/mm^2, 25.08N/mm^2, and 24.74N/mm^2. Comparatively, there are percentage decreases in strength (i.e over that of the normal cubes) of 27.0%, 14.7%, 13.5% and 24.5%. The graph of the affected cubes strength, 'G-Affected is shown in figure 4.1.1(a). However, unlike the previous graph, this graph has its first part a little bit deviated from the usual fairly straight line. This, and the fact that, the last compressive strength value is less than the preceeding value are attributed to the fact that, as the cement mortar continue to develop in strength, the aggressive medium on the other hand weakens the specimen by attacking the bonding ability of the cement. In the later case, this is so detrimental that the decrease in strength is greater in magnitude than the increase in strength. Consequently, there is a resulting decrease. At the initial curing ages, this is so (as indicated on the graph) because the sharp increase in strength is greater in magnitude than the loss in strength.

The strength results of the modified cubes are generally higher in magnitude than the affected cubes strength. Some of these results are even higher than the normal cube's strength of the same age (see Table 3.4.0). In fact, this is the positive effect of the introduced latex into the mix. However, with high percentage addition of the latex (i.e 3%) the strength values are lower than the corresponding values of the affected group. To this effect, two factors are evident:

(i.) The over sufficient latex contributes towards preventing the cement from 'fully' coating inert particles, thus, causing a weaker bondage between the particles.

(ii.) The pores occupied by the excess latex gives more room to the aggressive water after the processes of hydration and initial drying.

Figure 4.1.1(b) consists of the line graphs of the respective percentages of latex together with the graphs in 4.1.1(a). These graphs are identified as GM 1%, GM 1.5%, GM 2%, GM 2.5% and GM 3%.

From figure 4.1.1(b) GM. 1% started with a strength well above the GA and continued in that manner - clearly showing the effectiveness of the 1% latex added into the mix. In spite of the fact that there is a fall below GN about 40 days old, the addition of 1% is still an effective quantity in the matter of protecting the mortar against aggressive attack by possible ingress.

GM. 1.5% has all its values greater than similar values of the GN. Therefore, depicting one of the best graph among all others. In other words, the effect of 1.5% latex has a remedial capacity of making the mortar to be stronger than the normal mortar even under the aggressive environment.

GM. 2% falls between GN and GA at the initial stage, but as the GM 2% steeper than GN, it crosses the GN at about 50 days old. This graph (GM. 2%) has all extended possible future increase in strength with an equally possible indications of maintaining the lap between the two. Thus, the overall possible future strength protection capacity of this amount (2% latex) will be such that, the mortar will be stronger than the normal mortar.

GM. 2.5% when compared with the above graphs, has shown a fall in strength at the initial age and throughout the curing age. Though there is really a marked protection qualities by this percentage latex (i.e 2.5%) there is a clear indications (i.e. by virture of a low strength retained) that, the amount is not as effective as the foregone percentage. Similar is the case with the last graph (GM. 3%).

4.1.2 MORTAR STRENGTH (RATIO 1:6)

Ratio 1:6 mix is generally weaker in strength when compared with the mix of ratio 1:3. A typical example of the differences in strength between the two is seen in the 7 day normal cube's strength; 5.42N/mm^2 as against 24.74N/mm^2 for the ratios 1:6 and 1:3 mixes respectively.

Gn is synonymous to GN but, for the ratio 1:6. The results that constitutes the Gn-graph ranges from 5.42N/mm^2 to 6.25N/mm^2 - belonging to the first curing age and the last curing age in that order. The maximum increase in strength of this mix ratio between the first and the last observed strength which is also the interval between the mix. However, by contrast, twice the cement in ratio 1:6 mix is in ratio 1:3 mix. Therefore, the doubling of the percentage increase in the ratio 1:6 mix by ratio 1:3 mix is not unaccounted for.

The shorter interval presented by the Gn results (as compared to GN results) makes the Gn-graph less steep relative to the GN-graph. The Gn-graph is shown in figure 4.1.2(a).

The graph representing the results of the affected cubes of the ratio 1:6 mix is also shown in this figure. It is labelled Ga and it appears like Gn-graph, but, a little steeper.

Figure 4.1.2(b) consists of all the line graphs belonging to the modified groups of the ratio 1:6 mix. This is in addition to the line graphs of the normal and affected cubes (i.e 4.1.2(a)). The graphs of the modified cubes are identified as Gm.1% Gm.1.5%, Gm.2%, Gm.2.5% and Gm.3%. This is in accordance with the amount of latex added into the mix.

Gm.1% represents the results of the effect of 1% latex on the cubes. It started with strength equal to that of the affected cubes (i.e. without a show of the effect of the protective substance). However, it went as far as maintaining a close and parallel position with the Gn-graph.

Gm.1.5% is for the results of the effect of 1.5% latex on the cubes. Unlike the previous graph, this started with a show of the effect of the protective substance (i.e with a strength greater than that of Ga). The graph took just about the period of 18 days to cross the Gn, witha continuous possibility of maintaining its position. Therefore, an addition of 1.5% latex proves to be useful.

Gm.2% consisted of an initial strength value greater than the initial strength value of Gn. The 2% latex has therefore an effective protective qualities so large that it even produces a mortar of higher strength than the normal mortar throughout. This is seen right at the initial curing age (i.e 7 days), up to the last observed curing age. Another important factor attributed to this graph is the fact that the tendency of possible future fall in strength is not witnessed.

Gm.2.5% presents the graphical effect of 2.5% latex on the cubes. The initial strength figure is $4.61 N/mm^2$ which shows an effective protecive qualities of less than half that showed by the 2% latex. However, this graph depicted the highest stiffness that resulted in producing a graph showing the best form of protection capability by the latex. In fact the graph exhibited the highest degree of all the percentages in both mixes. The graph has also given a pattern that will continue to ascend (rather than to descend) in the future age.

Gm.3% is for the 3% latex. This graph has shown a similar behaviour like similar graph of ratio 1:3 mix in the sense of their initial nature. However, this graph crosses both Ga and Gn. which shows a fall in the protection capability.

Finally, all the modified cube's strengths of the mortar of ratio 1:6 mix were of magnitude greater than the affected cube's strength except one (i.e. the strength of the 7 day 3% latex). That means, all the percentages of latex added to the 1:6 mortar were of positive effect to the mortar, except that mentioned above.

4.1.3 OPTIMUM AMOUNT OF LATEX

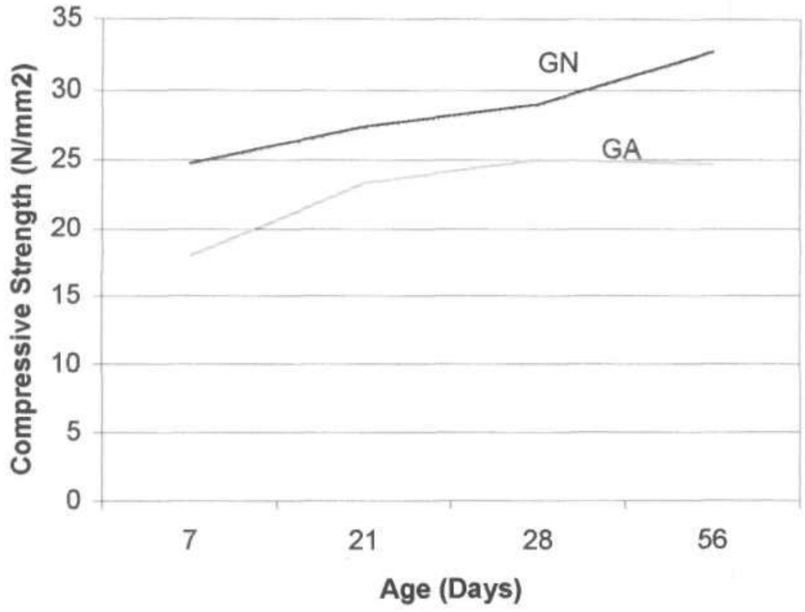
From the discussion so far, the optimum percentage of latex additions are 1.5% and 2.5% for ratios 1:3 and 1:6 mixes respecively. These are clearly shown by means of bar charts.

Table 4.1.3

LATEX ADDITION

Mix	Curing Period	Strength (N/mm²) (Optimum Latex%)		Different in Strength	Percentage Different
1:3	7	18.06	27.42	9.36	51.8%
	21	23.41	29.43	6.02	25.7%
	28	25.08	30.09	5.01	20.0%
	56	24.74	33.77	9.03	36.5%
1:6	7	4.01	4.61	0.60	15.0%
	21	4.61	6.75	2.14	46.4%
	28	5.02	7.49	2.47	49.2%
	56	5.42	7.82	2.40	44.3%

Compressive Strength of the Mortar Cubes



4.1.1(a)

Compressive Strength of the Mortar Cubes

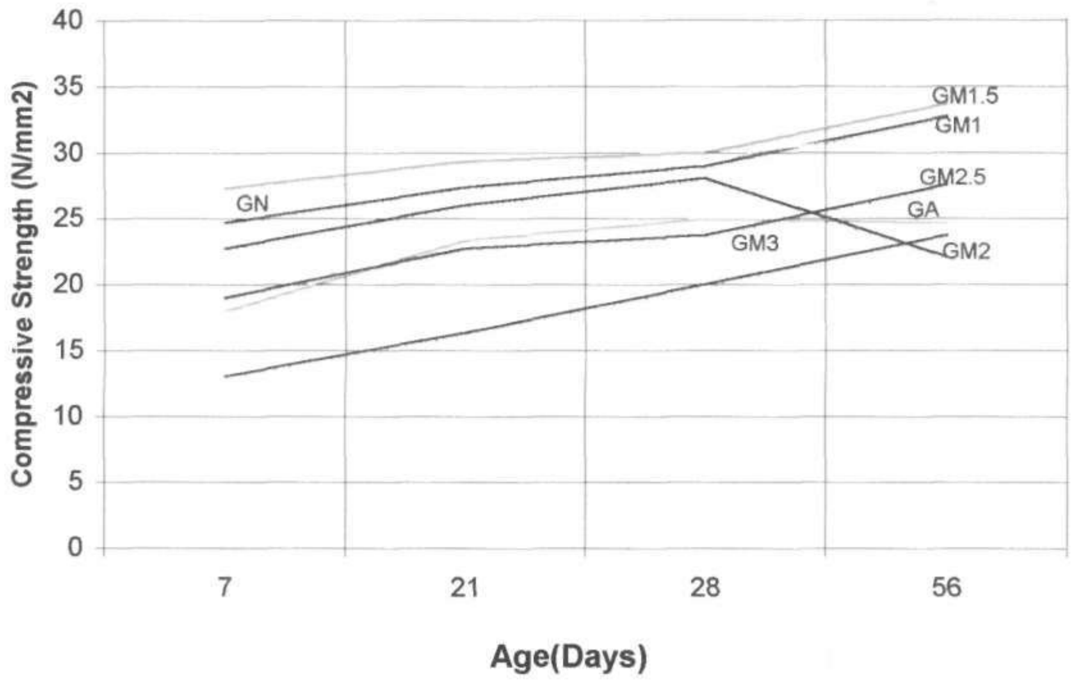


Fig. 4.1.1(b)

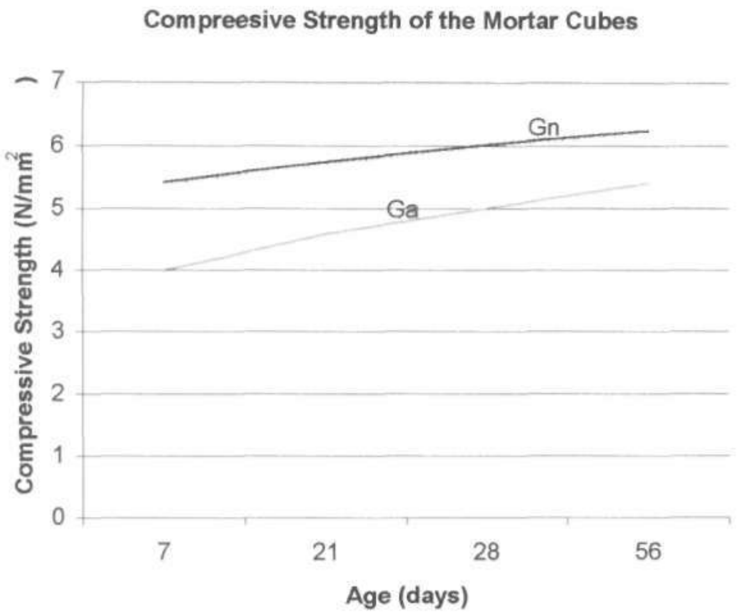


Fig 4.1.2(a)

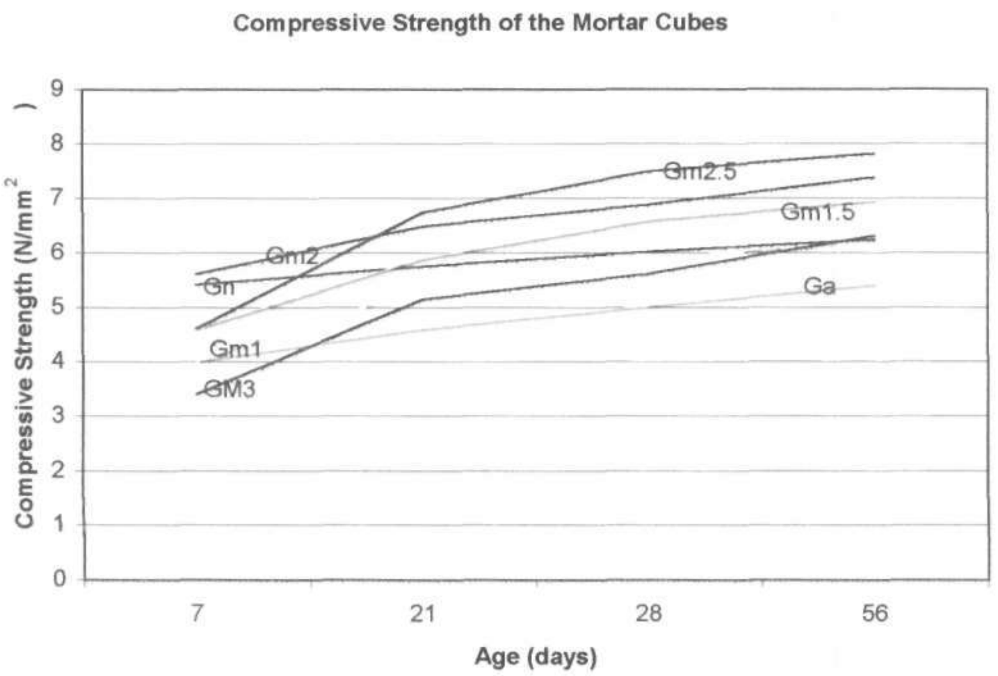


Fig 4.1.2(b)

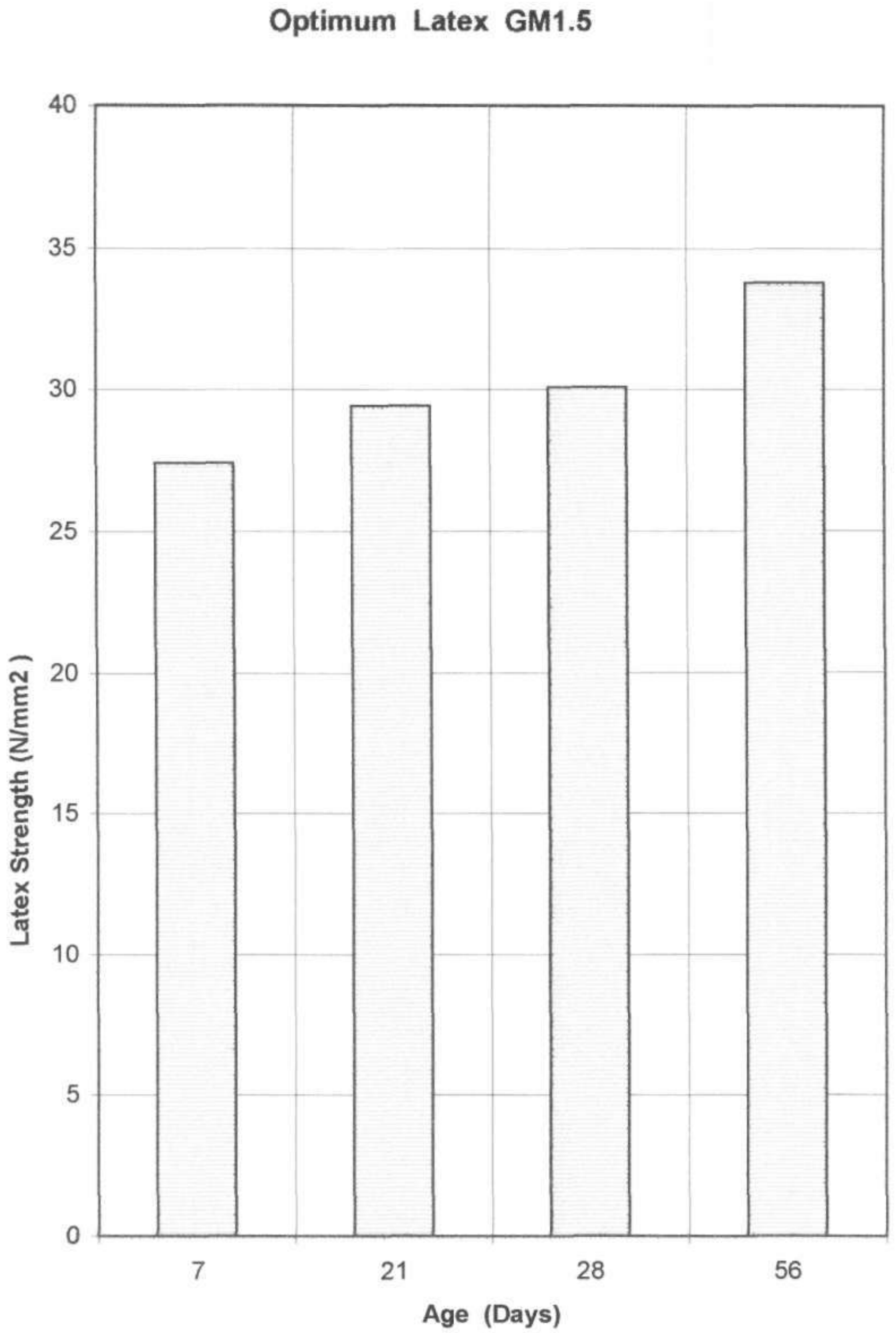
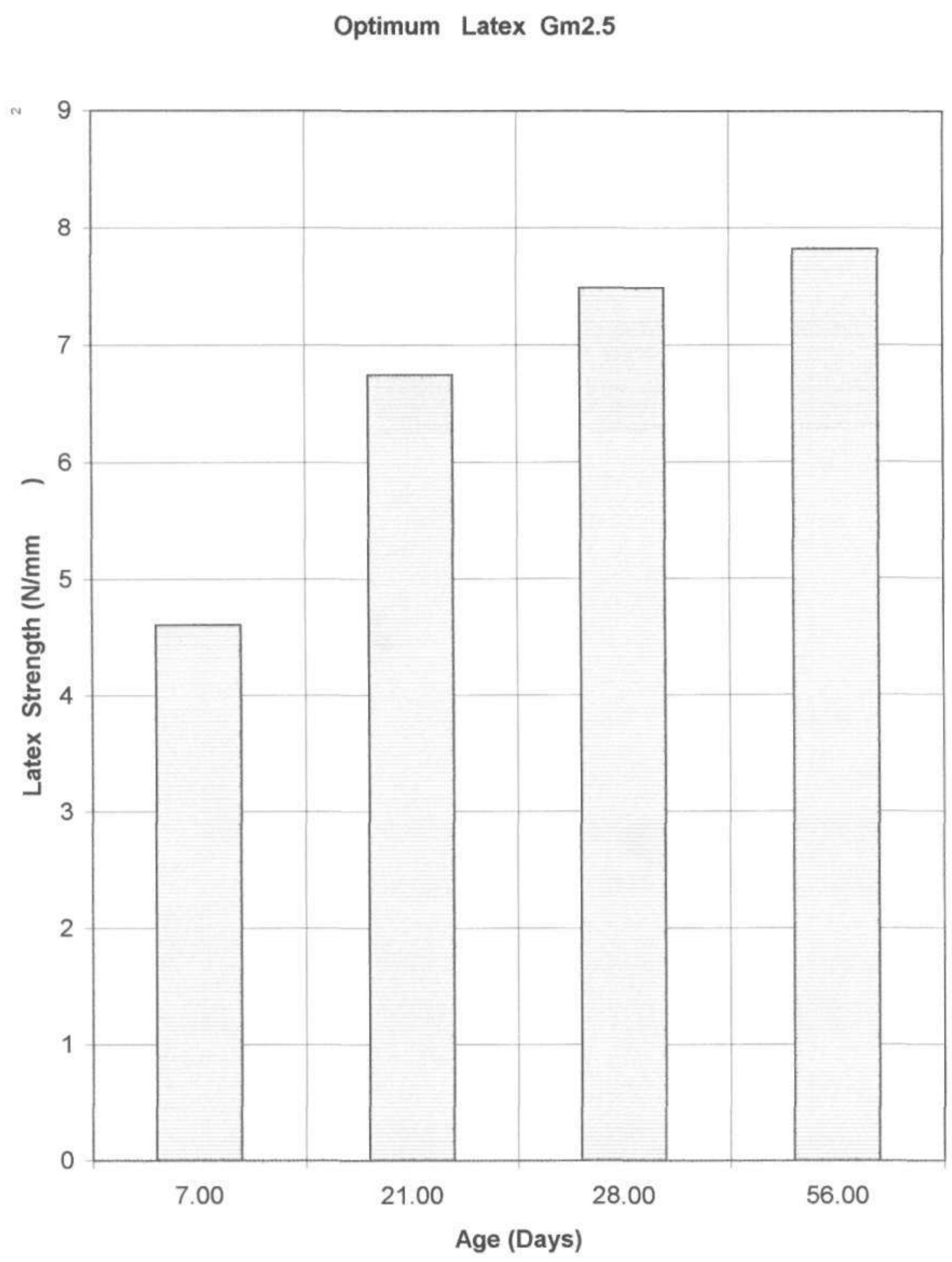

Optimum Latex GM1.5
40
35
30
25
20
15
10
5
0
Latex Strength (N/mm2)
7
21
28
56
Age (Days)

Fig. 4.1.3(a)



Optimum Latex Gm2.5
Latex Strength (N/mm 2)
9
8
7
6
5
4
3
2
1
0
7.00
21.00
28.00
56.00
Age (Days)

Fig. 4.1.3(b)

APPENDIX I

CUBE'S STRENGTH AFTER 7 DAYS OF IMMERSION

RATIO OF MIX 1:3

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
7 days	24.74/18.06	1%	26.75	48.12%
		1.5%	27.42	51.83%
	Loss Strength	2%	22.74	25.91%
	27.0%	2.5%	19.06	5.54%
		3%	13.04	-27.69%

CUBE'S STRENGTH AFTER 7 DAYS OF IMMERSION

RATIO OF MIX 1:6

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
7 days	5.42/4.01	1%	4.01	0%
		1.5%	4.61	14.96%
	Loss Strength	2%	5.62	40.15%
	260%	2.5%	4.61	14.96%
		3%	3.41	-14.96%

CUBE'S STRENGTH AFTER 21DAYS OF IMMERSION

RATIO OF MIX 1:3

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
21days	27.43/23.41	1%	28.75	22.81%
		1.5%	29.43	25.72%
	Loss Strength	2%	26.08	11.41%
	14.7%	2.5%	22.74	-2.86%
		3%	18.39	-21.44%

CUBE'S STRENGTH AFTER 21 DAYS OF IMMERSION

RATIO OF MIX 1:6

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
21 days	5.75/4.61	1%	5.35	16.05%
		1.5%	5.89	27.77%
	Loss Strength	2%	6.49	40.78%
	19.8%	2.5%	6.75	46.42%
		3%	5.15	11.71%

CUBE'S STRENGTH AFTER 28 DAYS OF IMMERSION

RATIO OF MIX 1:3

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
28 days	29.09/25.08	1%	29.43	17.34%
		1.5%	30.09	19.98%
	Loss Strength	2%	28.09	12.0%
	13.8%	2.5%	23.74	-5.34%
		3%	20.06	-20.02%

CUBE'S STRENGTH AFTER 28 DAYS OF IMMERSION

RATIO OF MIX 1:6

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
28 days	6.02/5.02	1%	5.92	17.93%
		1.5%	6.59	31.27%
	Loss Strength	2%	6.89	37.25%
	16.6%	2.5%	7.49	49.20%
		3%	5.62	11.95%

CUBE'S STRENGTH AFTER 56 DAYS OF IMMERSION

RATIO OF MIX 1:3

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
56 days	32.77/24.74	1%	32.10	29.75%
		1.5%	33.77	36.5%
	Loss Strength	2%	33.10	33.79%
	24.5%	2.5%	27.62	11.64%
		3%	23.74	-4.04%

CUBE'S STRENGTH AFTER 56 DAYS OF IMMERSION

RATIO OF MIX 1:6

Immersion Period	Normal/Affected Cube's Strength (N/mm^2)	Rubber Latex (%) (by weight)	Modified Cube's Strength (N/mm^2)	Difference in Strength (%)
56 days	6.25/5.42	1%	6.15	13.47%
		1.5%	6.96	28.41%
	Loss Strength	2%	7.39	36.35%
	13.3%	2.5%	7.82	44.28%
		3%	6.32	16.61%

APPENDIX II

1(a): WEIGHT

CM = 1, CA = 1, RM = 1 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{11}	793	804	11	
Y_{10}^{11}	795	806	11	$W_{10}^{11} = 10.7$
Z_{10}^{11}	795	805	10	

1(b): WEIGHT
CM = 2, CA = 1, RM = 1 PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{21}	790	802	12	
Y_{10}^{21}	790	803	13	$W_{10}^{21} = 12.0$
Z_{10}^{21}	801	812	11	
X_{11}^{21}	796	806	10	
Y_{11}^{21}	790	800	10	$W_{11}^{21} = 10.7$
Z_{11}^{21}	799	811	12	
X_{12}^{21}	793	800	7	
Y_{12}^{21}	799	805	6	$W_{12}^{21} = 6.7$
Z_{12}^{21}	794	801	7	
X_{13}^{21}	795	801	6	
Y_{13}^{21}	790	801	11	$W_{13}^{21} = 8.3$
Z_{13}^{21}	794	802	8	
X_{14}^{21}	792	801	9	
Y_{14}^{21}	792	803	11	$W_{14}^{21} = 10.3$
Z_{14}^{21}	800	808	8	
X_{15}^{21}	795	807	12	
Y_{15}^{21}	785	800	15	$W_{15}^{21} = 10.3$
Z_{15}^{21}	790	803	13	

2(a): WEIGHT

CM = 1, CA = 1, RM = 2 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{11}	685	719	34	
Y_{20}^{11}	683	715	32	$W_{20}^{11} = 37.7$
Z_{20}^{11}	661	708	47	

2(b): WEIGHT

CM = 2, CA = 1, RM = 2 PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{21}	681	712	31	
Y_{20}^{21}	655	700	45	$W_{20}^{21} = 44.7$
Z_{20}^{21}	684	715	58	
X_{21}^{21}	679	717	38	
Y_{21}^{21}	678	720	42	$W_{21}^{21} = 36.3$
Z_{21}^{21}	673	712	29	
X_{22}^{21}	672	712	40	
Y_{22}^{21}	678	710	32	$W_{22}^{21} = 35.7$
Z_{22}^{21}	665	700	35	
X_{23}^{21}	662	697	35	
Y_{13}^{21}	665	702	37	$W_{23}^{21} = 33.7$
Z_{13}^{21}	667	694	27	
X_{24}^{21}	686	715	29	
Y_{24}^{21}	690	719	29	$W_{24}^{21} = 30.3$
Z_{24}^{21}	690	723	33	
X_{25}^{21}	690	710	20	
Y_{25}^{21}	672	717	45	$W_{25}^{21} = 33.3$
Z_{25}^{21}	693	728	35	

3(a): WEIGHT

CM = 1, CA = 2, RM = 1 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{12}	799	816	17	
Y_{10}^{12}	766	805	19	$W_{10}^{12} = 17.3$
Z_{10}^{12}	790	806	16	

3(b): WEIGHT

CM = 2, CA = 1, RM = 1 PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{22}	800	817	17	
Y_{10}^{22}	785	802	17	$W_{10}^{22} = 18.3$
Z_{10}^{22}	781	802	21	
X_{11}^{22}	771	785	14	
Y_{11}^{22}	783	792	9	$W_{11}^{22} = 17.7$
Z_{11}^{22}	770	800	30	
X_{12}^{22}	782	805	23	
Y_{12}^{22}	793	805	12	$W_{12}^{22} = 16.3$
Z_{12}^{22}	795	809	14	
X_{13}^{22}	800	817	17	
Y_{13}^{22}	810	820	10	$W_{13}^{22} = 16.7$
Z_{13}^{22}	795	818	23	
X_{14}^{22}	764	785	21	
Y_{14}^{22}	778	798	21	$W_{14}^{22} = 19.0$
Z_{14}^{22}	781	796	15	
X_{15}^{22}	776	795	19	
Y_{15}^{22}	785	801	16	$W_{15}^{22} = 23.0$
Z_{15}^{22}	744	775	31	

4(a): WEIGHT

CM = 1, CA = 2, RM = 2 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{12}	680	738	58	
Y_{20}^{12}	679	741	62	$W_{20}^{12} = 58.7$
Z_{20}^{12}	684	740	56	

4(b): WEIGHT

CM = 2, CA = 2, RM = 2 PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{21}^{22}	674	761	87	
Y_{21}^{22}	686	745	59	$W_{20}^{22} = 74.0$
Z_{21}^{22}	682	758	76	
X_{21}^{22}	652	717	65	
Y_{21}^{22}	668	718	50	$W_{21}^{22} = 56.0$
Z_{21}^{22}	677	730	53	
X_{22}^{22}	662	719	57	
Y_{22}^{22}	657	710	53	$W_{22}^{22} = 53.3$
Z_{22}^{22}	666	716	50	
X_{23}^{22}	674	730	56	
Y_{23}^{22}	689	730	41	$W_{23}^{22} = 46.7$
Z_{23}^{22}	683	726	43	
X_{24}^{22}	675	730	55	
Y_{24}^{22}	678	740	62	$W_{24}^{22} = 60.0$
Z_{24}^{22}	688	751	63	
X_{25}^{22}	663	730	67	
Y_{25}^{22}	670	728	58	$W_{25}^{22} = 64.3$
Z_{25}^{22}	662	730	68	

5(a): WEIGHT
CM = 1, CA = 3, RM = 1 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{13}	788	809	21	
Y_{10}^{13}	792	810	18	$W_{10}^{13} = 19.3$
Z_{10}^{13}	804	823	19	

5 (b): WEIGHT
CM = 2, CA = 3, RM = 1, PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{23}	784	812	28	
Y_{10}^{23}	790	815	25	$W_{10}^{23} = 24.7$
Z_{10}^{23}	789	809	20	
X_{11}^{23}	798	825	27	
Y_{11}^{23}	810	825	15	$W_{11}^{23} = 20.2$
Z_{11}^{23}	793	812	19	
X_{12}^{23}	769	792	23	
Y_{12}^{23}	792	808	16	$W_{12}^{23} = 18.0$
Z_{12}^{23}	785	800	15	
X_{13}^{23}	757	777	20	
Y_{13}^{23}	765	785	20	$W_{13}^{23} = 21.0$
Z_{13}^{23}	770	793	23	
X_{14}^{23}	771	785	14	
Y_{14}^{23}	744	775	31	$W_{14}^{23} = 23.0$
Z_{14}^{23}	748	792	44	
X_{15}^{23}	740	782	42	
Y_{15}^{23}	785	705	20	$W_{15}^{23} = 25.7$
Z_{15}^{23}	755	780	25	

6(a): WEIGHT

CM = 1, CA = 3, RM = 2 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{13}	656	733	77	
Y_{20}^{13}	655	728	73	$W_{20}^{13} = 70.7$
Z_{20}^{13}	665	727	62	

6 (b): WEIGHT

CM = 2, CA = 3, RM = 2, PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{23}	655	751	96	
Y_{20}^{23}	667	747	80	$W_{20}^{23} = 78.7$
Z_{20}^{23}	671	730	59	
X_{21}^{23}	663	735	72	
Y_{21}^{23}	662	732	70	$W_{21}^{23} = 70.0$
Z_{21}^{23}	680	748	68	
X_{22}^{23}	667	739	72	
Y_{22}^{23}	669	740	71	$W_{22}^{23} = 70.0$
Z_{22}^{23}	660	727	67	
X_{23}^{23}	655	728	63	
Y_{23}^{23}	657	721	64	$W_{23}^{23} = 69.0$
Z_{23}^{23}	655	725	70	
X_{24}^{23}	654	720	66	
Y_{24}^{23}	645	717	72	$W_{24}^{23} = 65$
Z_{24}^{23}	663	720	57	
X_{25}^{23}	635	717	82	
Y_{25}^{23}	671	729	58	$W_{25}^{23} = 65$
Z_{25}^{23}	670	725	55	

7(a): WEIGHT

CM = 1, CA = 4, RM = 1 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immerr	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{14}	795	815	20	
Y_{10}^{14}	792	808	16	W_{10}^{14} = 19.3
Z_{10}^{14}	792	814	22	

7 (b): WEIGHT

CM =2, CA = 4, RM = 1, PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{10}^{24}	792	817	25	
Y_{10}^{24}	779	810	31	W_{10}^{24} = 27.7
Z_{10}^{24}	795	822	27	
X_{11}^{24}	795	812	17	
Y_{11}^{24}	774	789	15	W_{11}^{24} = 17.3
Z_{11}^{24}	795	815	20	
X_{12}^{24}	780	789	9	
Y_{12}^{24}	782	800	18	W_{12}^{24} = 17.7
Z_{12}^{24}	780	800	20	
X_{13}^{24}	738	760	22	
Y_{13}^{24}	728	773	45	W_{13}^{24} = 29.2
Z_{13}^{24}	719	716	41	
X_{14}^{24}	776	782	6	
Y_{14}^{24}	744	791	47	W_{14}^{24} = 31.0
Z_{14}^{24}	740	780	40	
X_{15}^{24}	740	790	50	
Y_{15}^{24}	730	788	58	W_{15}^{24} = 42.7
Z_{15}^{24}	758	798	40	

8(a): WEIGHT

CM = 1, CA = 4, RM = 2 PL = 0

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{14}	662	749	87	
Y_{20}^{14}	665	749	84	$W_{20}^{14} = 85.7$
Z_{20}^{14}	668	754	86	

8 (b): WEIGHT

CM = 2, CA = 4, RM = 2 PL = 0 to 5

CUBE'S ID. MARK	CUBE'S WEIGHT (grm) B/4 Immer.	A/T Immer.	WEIGHT OF WATER (grm)	AVERAGE WEIGHT OF WATER (grm)
X_{20}^{24}	656	747	91	
Y_{20}^{24}	666	747	81	$W_{20}^{24} = 84.7$
Z_{20}^{24}	666	742	82	
X_{21}^{24}	644	729	85	
Y_{21}^{24}	660	738	84	$W_{21}^{24} = 83.2$
Z_{21}^{24}	657	744	81	
X_{22}^{24}	672	750	78	
Y_{22}^{24}	675	740	65	$W_{22}^{24} = 78.2$
Z_{22}^{24}	663	756	93	
X_{23}^{24}	662	732	70	
Y_{23}^{24}	660	735	75	$W_{23}^{24} = 76.7$
Z_{23}^{24}	655	740	85	
X_{24}^{24}	668	740	72	
Y_{24}^{24}	664	739	75	$W_{24}^{24} = 74.0$
Z_{24}^{24}	662	737	75	
X_{25}^{24}	660	736	76	
Y_{25}^{24}	663	738	75	$W_{25}^{24} = 75.3$
Z_{25}^{24}	668	743	75	

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1.0 CONCLUSIONS

Chapters one to four of this research comprises all the necessary information about the research. Based upon the findings of the research, the following conclusions were made:

1. Normal mortar cubes (i.e. cubes without latex) immersed in water gained a continuous increase in compressive strength from 24.74N/mm^2 to 32.77N/mm^2 at the end of the 56 days curing period for the ratio 1 : 3 mix and from 5.42/mm^2 to 6.25N/mm^2 at the end of a similar curing age for the ratio 1 : 6 mix. But, similar cubes immersed in the aggressive water decreased appreciably (in compressive strength) to values as low as 18.06N/mm^2 and 24.74N/mm^2, against the above strength values for the ratio 1 : 3 mix. The affected cubes strength for the ratio 1 : 6 mix are 4.01N/mm^2 and 5.452N/mm^2 as against the non-affected strength values for the same ratio mentioned above.
2. However, cubes with varying proportions of latex immersed in the aggressive water, maintained higher strength values than those observed from the control cubes, except cubes with the highest percentage of latex (i.e. 3% latex). The highest strength figures observed for the ratio 1 : 3 mix are; 27.42N/mm^2 - 7 days immersion period and 33.77N/mm^2 - 56 days immersion period, i.e., with increase in strength of 51.8% and 36.5% respectively.

   Similarly, percentage increases of 114% and 289% were observed from cubes of the ratio 1 : 6 for the 7 days and 56 days immersion periods.
3. The amount of water absorbed by cubes immersed in the tap water is less than that absorbed by similar cubes immersed in the dam water. For example, the water content of a simple from the normal cubes is 58g, as

against 83g for identical samples from the affected cubes. Similar is the case with all other samples.

4. The amount of water absorbed by the modified cubes varies depending upon the quantity of latex introduced into the mortar. Generally, modified cubes with percentage latex of the highest strength group, absorb less water than non modified cubes, in fact a close observation reveals that there is a relationship between strength of the cubes and the water absorbed by the cubes. i.e.. the more the water absorbed, the less the strength.

5.2.0 RECOMMENDATIONS

Based upon the findings of this research the followings are recommended:

1. Cement mortar and similar materials particular concrete, should be protected with rubber latex in situations where possible ingress of aggressive moisture is anticipated.
2. The amount of latex to be used should be 1.5% for ratio 1 : 3 mix and 2.5% for ratio 1 : 6 mix-cement sand (river washed) in both cases.

5.3.0 SUGGESTIONS FOR FURTHER RESEARCH

1. Investigations using other forms of latex like acacia-tree, bituminous materials or gloss paint may be helpful so as to determine the best form of protection against the chemical attack.
2. This work can be extended to cover reinforced concrete structures.

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