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Assessment of roof waterproofing by pre-packaged polymer modified slurry (PPPMS) and bitumen

Safdar Iqbal*[1] Beenish Jehan[1a], Fasih Ahmed Khan[2b]
Haris Khan[1c]and Sarmad Ali Khan[1d]

[1]CECOS University of I.T and Emerging Sciences, Peshawar, Pakistan
[2]Department of Civil Engineering, University of Engineering &Technology, Peshawar, Pakistan

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Abstract. Effective waterproofing of structures was a compulsory constraint to avoid leaks and dampness or humidity in walls, ceilings, roofs underground tank and underground room. Traditionally used methods of roof waterproofing were bitumen with tinny seared clay tiles are very troublesome, overwhelming time and involving high labor cost. These waterproofing methods are not allocation the purpose due to their intrinsic disadvantages. Prepackaged polymer modified slurries (PPPMS) are now attainment the vogue and easy to use, easily available in the market, cheaper in cost and more workable than the traditional methods of waterproofing. An experimental study has shown that prepackaged polymer modified slurries (PPPMS) are superior in cost and performance to as a roof water proof coatings. Bituminous coatings were mixed with water and different combination of prepackaged polymer modified slurries and primer respectively, to find optimum coverage underneath worst atmospheric conditions. Every specimen of different proportioned was applied on plane roofs and through the passage of time, their performance was checked, assessed and associated with each other. The roof of approximately 40000 ft^2 area of prepackaged polymer modified slurries was used will give us hundred percent result (no water seepage or no water absorption) therefore no complaints as compare to roofs area of approximately 24000 ft^2 bituminous coating was used for waterproofing they have shown the result of 30 to 40 percent water seepage. This result shows that prepackaged polymer modified slurries were two times cheaper than bituminous coating. Comparing an equal number of surfaces coated with a polymer modified prepackaged mortar and bitumen the prepackaged polymer modified slurries (PPPMS) showed excellent performance, ease of application and low bitumen coating cost.

Keywords: pre packaged polymer modified slurry (PPPMS); bitumen; water proofing; roof waterproofing; coating

1. Introduction

∗Corresponding author, Graduate Student, E-mail: safdariqbal006@gmail.com
[a]Assistant Professor, E-mail: beenish@cecos.edu.pk
[b]Lecturer, E-mail: fasihahmad@uetpeshawar.edu.pk
[c]Graduate Student, E-mail: Haris5387279@gmail.com
[d]Engineer, E-mail: gandapur589@gmail.com

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Leaking from the top of the roof and the edges or corners of houses, hospitals, tall buildings, was the most common problem. During the execution phase of the structural unit, the age of the building or inadequate management was initiated by the influence of bad weather and design. Now a day roof leaking was flattered a great matter of attention as it can completely twist your boost/ aesthetics and also very dangerous for human health.

The publications (Verrall 1996, Phinney *et al.* 2001, Kirkpatrick and Kiernan 2006, Chen *et al.* 2012, Talib *et al.* 2015, Othman *et al.* 2015, Kot *et al.* 2016) were also discussed roof leakage/seepage problems and their solution.

The roof had to be protected with waterproof materials and additional benefits were needed such as energy efficiency, automatic sealing, shrinkage and cracking in concrete.The publications (Combrinck *et al.* 2018, Bogdanov and Ibragimov 2017, Xue *et al.* 2015a, b, Song 2016, Plachy *et al.* 2019, Singh *et al.* 2004, Plachý *et al.* 2018, Wong and Hui 2005) were explained different roof watertight materials, their importance, and properties. The research work includes the evaluation of modified polymer suspension bitumen in the application method, the assessment of costs, compensation and deficiencies, and the protective equipment to be taken during the construction phase (Marques *et al.* 2011, Kalkanoglu 1993, Kehr *et al.* 1987).

The roof was the top surface of a building or structure to protect it from the weather. The roof of the building is exposure to weather conditions and will be directly affected by the wind, rain and sun stones. The roof of the building is constructed in such a way that rain water can easily flow through drainage pipes of sufficient diameter to allow the building to be removed from the roof without moisture in the roof, walls and adjacent buildings for different purposes (Abdulla and Al-Shareef, 2009, Chilton *et al.* 2000, Villarreal and Dixon 2005, Zimmerman *et al.* 2006, Zhang *et al.* 2009). Waterproofing was the mixture of constituents or arrangements, that was aimed to avoid water inflowing or escaping from different sections of house or structures (Combrinck *et al.* 2018, Bogdanov and Ibragimov 2017, Xue *et al.* 2015a, b, Song 2016, Plachy *et al.* 2019, Singh *et al.* 2004, Plachý *et al.* 2018, Wong and Hui 2005).

A major influential factor in the leakages of the roof was inactivity of roof water due to ripple in the roof surface, insufficient number and size of openings, bracing of drainage lines, indecorous detailing at the junction of roof and parapet and development or construction joints were not joined as per the suggested description (Talib *et al.* 2015, Wong and Hui 2005). Mortars were generally prepared from Portland cement; it was common construction material (Powers and Brownyard 1946). However, the cement mortar has some disadvantages, such as low tensile strength, late reinforcement, low chemical resistance and significant shrinkage during drying. Several control methods were used to reduce these defects. The polymer modified slurry was prepared using a conventional cement mortar and some additional materials such as liquid resins, fly ash, iron residues, latexes, steel slag, and recombinant polymer powders (Liu *et al.* 2014, Ōhama *et al.* 1964).

Higher story building roofs were fats roofs. Topmost of these roofs were made of waterproof by waterproofing materials such bitumen membrane, mature of waterproofing slurries in concrete, etc. by trustworthy techniques of waterproofing. There should be the least deviation in pitch over the whole roof. It was better to have an unvarying fall over the whole roof. Providing steeper falls near the border of the roof should be evaded in order to avoid the collection of water at the juncture between the house roof slab and parapet wall, as this connection was disposed to water leakage (Ustinovichius *et al.* 2012). A building, houses and any other structures required waterproofing, concrete itself was not sufficient to resist or protect the roof from seepage.

The entire flat roofs were generally constructed from reinforced cement concrete and it should

be made watertight by using numerous methods for roof waterproofing (Talib *et al.* 2015, Xue *et al.* 2015a, b, Bogdanov and Ibragimov 2017). Important factors affecting the humidity caused by roofs in the ceilings were: demolition, capillary movement, inadequate drainage of sediments, water leaking from cracks in the external plaster, unsuitable cement mortars in the upper part.

2. Literature review

Construction of contemporary residence elements like houses or apartment, bedsitters can be marked out from natural caves. This was the easiest way for accommodation. Conventional houses types have a progressive response to be needed. They have a skill full mason of the expert in stone working. They were also look out a specific aspect of construction procedure, knowledge, and its maintenances and that too of waterproofing of flat roofs (Gonçalves *et al.* 2019, Leccese *et al.* 2019, Nečas 2018, Bogdanov and Ibragimov 2017). Roofs were used drying clothes, storage, parties and so on. Such a useful area because it was an unwanted source of water caused by moisture from sewage or sometimes rain. It was a unique way to build a sloping roof instead of a flat roof. The development of a new design and modern building materials ensures that the roof is waterproof and sustainable. (Zhu *et al.* 2019, Plachý *et al.* 2018, Talib *et al.* 2015).

South Punjab is hot and dry, and the center of Punjab was a hot and rainy climate. The climate condition was clearly in two phases. In the warmed part of the year, the temperature reached up to 55 C^{o} and sore for life (Ali *et al.* 2019). Therefore it gives the impression for the roof we required two barricades, one resist of hotness and another resist of rainwater. The old style method has been delivering 6 to 8 inches of mud lair and lace 1.50 to 2 inches thick clay tile on top of mud and grouts the gap with cement. Such a layer function a dual purpose of weathering and water tightness. Reinforced concrete slabs are poured from normal cement concrete without the use of an auxiliary material to provide the additional maneuverability required for proper placement and compaction of the concrete on the blocked reinforcement. From time to time, the main waterproofing mixtures were used in concrete (Tittarelli and Moriconi, 2008, Newman and Choo 2003). But frequently it was not used appropriately or adequately. There are mud and terracotta tiles on the roofs of the apartments for two reasons: waterproofing and secondly roof insulation. This top sheet is designed for slope drainage to facilitate discharge of sediments. Parapet, as a rule, is made of brick and covered with ordinary Portland cement mortar. The inadequate compaction, frequently the concrete of the RCC slab was full of cavities due to honeycombing phenomena. When the water spreads the RCC slab, that one easily leaks inside and rusts the reinforcements, and weakens the structure. Once seeping over the RCC slab, water makes wet the walls and ceiling. In major condition water twitches soaked on the roof. Entirely the unpleasant covers of humidity on the walls and ceiling, and coats peek off (Sharma *et al.* 2010, Bhaskar *et al.* 2007).

All water that comes in the roof should be channeled into roof fixtures that fall into stormwater sewers via a system of downpipes stormwater pipes should preferably be constructed of cast iron. UPVC, asbestos, galvanized sheet, shall be securely fixed. The rainwater pipes should be fixed to the external side of the walls of the house. All folds of the drain pipes must be aligned on terraces outside the inner surface of the railings. Ana, keep them clean. When the rainwater pipe passes through the slabs, a funnel with anticorrosive material must be provided to prevent water from seeping into the structure from corrosion. The required number of discharge pipes has been provided and their diameter must be selected according to the average rainfall specified in the National Construction Code (NCC). The bell outlet must be secured and adjusted correctly to

allow water to enter. If possible, leaves, stones and so on. Place a cap in the hole to avoid hitting it.

3. Material selection for roof waterproofing

Roof waterproofing divided into two methods.
- Conventional Method
- Modern Method

The main materials for conventional method were.
- Bitumen
- Polythene Rolls
- Mud
- Brick Tile
- Cement and Sand

The main materials for modern method were.
- Pre Packaged Polymer Modified Slurry
- Polythene Rolls
- Mud
- Brick Tile
- Cement and Sand

The selection of waterproofing membrane should consider the type of loading on the roof as public access or vehicular traffic, environmental exposures, thermal insulation and aesthetics different membrane have their own characteristic and the choice of a particular membrane depends on the main properties such as tensile strength, elongation, cracks linking competencies, weathering and UV resistance, easiness of application, puncture resistance and expected life, where applicable. The other properties were chemical and alkali resistance, good relationship (bonding) strength, little water absorption, enduring hydrostatic pressure, penetrable to vapor diffusion, good color preservation and algae and fungus resentence. In a particular generic base of the material the active soiled contents need to be checked for its effective performance .the final dry film thickness of the liquid applied membrane was important an depends upon active solid contents of the material.

Bitumen felts were the most common products for roof waterproofing. Tar/bitumen felts were categorized on types 1, 2, 3. These types depend on their manufacturing usage for which the felts were suitable. The bitumen felts should be laid over the finished roof surface, not on the sloped surface. Due to weather condition, the treatments of waterproofing consist of four sequences as shown in Table 1.

The modified polymer was the acrylic-based cementitious waterproofing and a defensive coating. Its composition was of the good quality of portland cement, classified and correctly selected aggregates extracts and acrylic emulsion polymer as a binder (Aggarwal *et al.* 2007).

3.1 Rainfall data

The rain fall data was collected from Pakistan Metrological Department (PMD) and was useful for detecting how much rain water standing on top surface of the roof that affected and causes seepage. During the research study period (January 2015 - August 2015), there was significant rainfall during this 8-month period (Khan *et al.* 2014). The precise rainfall data was as shown in Table 2. PMD (2019).

Table 1 Bitumen felt usage

Serial No.	Descriptions	Bitumen felt usage (kg/m^2 cm^3/m^2)
1	Hot applied bitumen	@ 1.20-1.65 kg/m^2
2	Hot applied bitumen	@ 0.70-1.20 kg/ m^2
3	Hot applied bitumen	@ 0.0060-0.0080 cm^3/ m^2
4	For severe key structures and climatic conditions, the treatment should be provided as given below.	
	i. Hot applied bitumen	@1.45 kg/ m^2
	ii. Pea size gravel	@ 0.0080 /cm^3/ m^2

Table 2 Monthly rainfall data of Lahore

Serial No.	Month	Rainfall (mm)	Humidity (%)
1	January	19.9	43
2	February	34.6	45.5
3	March	73.6	53
4	April	03	39.7
5	May	31.7	42.2
6	June	39.7	47
7	July	242.3	71
8	August	193.5	78

4. Methodology

A lot of methods were used for the purpose of water proofing. But just to get more precise and sticking to my research project, it can be divided into two main categories.

i. Conventional Method
ii. Modern Method

4.1 Conventional method

The typical procedure for the conventional method was as follows.

First of all, a smooth surface of RCC flat roof was prepared for the application of bitumen. It should be noted that no dust or uneven surface was desired for the application of bitumen as the dust will not allow bitumen to sticks with the RCC surface. The following two types of bitumen can be used for roof water proofing given below.

i. Hot Bitumen
ii. Cold Bitumen

Cold bitumen can be readily produced by adding the right ratio of kerosene / gasoline. Then it is advisable to apply with a brush. In the case of hot bitumen, bitumen was first boiled at very high temperatures for 3-5 hours. This operation should be applied by highly professional and great care should be adopted while applying/ transporting the hard bitumen. After painting the entire roof with the bitumen, plastic polythene sheet was applied on the flat roof, and then immediately

Fig. 1 Waterproofing for roofs with bitumen felt

Fig. 2 Mixing of PPPMS slurry with water

Fig. 3 PPPMS and water

Table 3 Rate analysis of prepackaged polymer modified slurry

PPPMS(kg)	Water(Liter)	Cover area(ft^2)	Cover area (1 kg Slurry)	Rates / ft^2 Rs.
5	2.5	112	22.4	14.45
5	3	140	28	11.60
5	3.25	154	30.8	10.55
5	4	196	39.5	8.22
5	5	248	49.6	6.55

Table 4 Rate analysis of Bitumen

Bitumen (kg)	Primer (litter)	Covered area Primer (ft^2)	Covered area Bitumen (ft^2)	Cost/(ft^2) primer	Cost/(ft^2) Bitumen
1	1	23.5	5	3.8 Rs	23 Rs

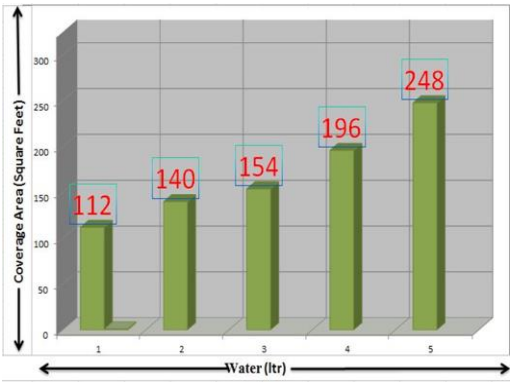

Fig. 4 PPPMS with different Proportions of water

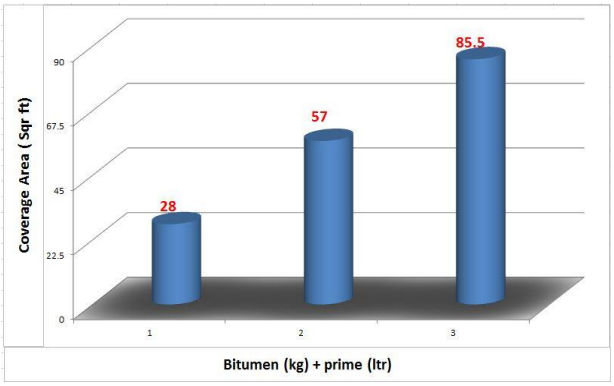

Fig. 5 Bitumen with different proportion of primer coverage

covered it with 4 to 6 inches of mud. Mud was used for the dual purpose in roof treatment.

i. For Heat Proofing/ thermal use

ii. For providing a slope for roof drainage

The second one was more important as it plays the role of the game changer. If the slope was

Fig. 6 Grouting of joints

Fig. 7 Smoothing of cement grouting

not appropriate, then rainwater can stagnate from the porous surface of brick tile (that was to be provided on top of mud). Once water seeps through the pores of the brick tile then it can easily be penetrated from the RCC flat roof and thus cause moisture problems at the interior surface of the house. After provided a 4 to 6 inches layer of mud, and after leveled in desire slope it was covered with brick tile (whose dimension as length=9" width=5" and height=1.5")inches. Then the joints of bricks tile were filled with 1:3 cement sand slurry. The slurry should be applied in such a way that it covers every brick tile in the same thickness. After 24 hours cured with wither try to avoid the formation of hairline cracks. The complete procedure as shown in Fig. 1.

4.2 Modern method

The modern procedure was pretty much the same as the conventional method, as the mud was used for the thermal and slope/ drainage purpose in both the methods. The main difference was the use of Pre Packaged Polymer Modified Slurry (PPPMS) instead of bitumen. PPPMS were consists of the cementitious mortar/ grout, packed in powdered form, which can be effectively used for waterproofing (Lanzón and García-Ruiz 2009). They were more workable, easy in handling and application, cheaper in cost as compared to any form of bitumen. The only reason was that they were not popular in most of the rural areas of Punjab as they were new to the market. PPPMS were ready for applied on flat RCC roofs for the purpose of waterproofing as shown in Figs. 2-3.

Mud was used for two important purposes:

• Resistant to thermal changes
• For drainage purpose

By doing so the surface was less likely to be damaged by the pedestrian traffic differentiating the rough and smooth surface of the cement grout was shown the final surface after the smoothing and leveling of the cement grout. It can be seen in the picture that no joint/ brick tile was unfilled and show in Figs. 6 and 7.

5. Results and discussion

The samples of bitumen and Pre Packaged Polymer Modified Slurry (PPPMS) were applied on more than 50 houses. And the results have shown a huge difference after a trial period of 3 months. The bitumen was applied on more than 20 houses and there were clear seepage spots on the ceilings of the rooms, also some of the walls were also infected from the seepage. While Pre Packaged Polymer Modified Slurry (PPPMS) was applied on more than 30 houses. And it shows no noticeable visible seepage on the ceiling or on the walls.

5.1 Bitumen

The bitumen itself was a pure waterproof material. It can be never being dissolved in water. But its application was tough, time kayaking, required great skill and also extreme care must be adopted during and after its application. If bitumen was applied according to the specs but it will never serve the purpose if care should not be adopted after its application. The bitumen was a brittle material (once it's getting cold) and can easily be tempered. So during the steps of roof treatment, the bitumen can be chipped off from the flat roof surface. And that wear and tear can become a source of dampness. If the bitumen was to be applied for the waterproofing purpose it should be covered instantly with a thick polythene sheet and also mud was spread over it immediately applying after the polythene sheet. One thing was to be noted that during the spreading of mud no heavy equipment should be used, as it can cause the tearing of bitumen that will eventually cause dampness.

The Picture below in Figs. 8 and 9 shows the seepage on the internal walls of a room. The picture was shown that the paintwork was started to deteriorate as seepage prolongs. And this

Fig. 8 Water seepage below the roof of slab

Fig. 9 Seepage on the inner walls of the house due to improper water proofing

was just the starting point of the seepage it prolongs all the way to the floor and destroys all the paint off the wall.

Just as water seepage can distort the inner wall paints it can also destroy the outer weather sheet/graphic. It can be concluded that how a front facade/ back elevation of the residential building was distorted just because of poor roof treatment. Shown in Fig. 7.

5.2 Rate analysis of pre packaged polymer modified slurry

The Pre Packaged Polymer Modified Slurry (PPPMS) can be used with a different proportion. Its workability can easily be controlled by controlling the amount of water. Preferably the first coat should be thinner while the second coat was a bit thicker than the 1st one. Following was a precise and real-time analysis of PPPMS Cost to Coverage ratio with different proportions of water. As shown in Table 3. And result with different proportion of water was shown in figures and 5.

5.3 Rate Analysis of Bitumen

Like PPPMSS the bitumen was also comes in many forms and origins. The method of application and amount of petrol/ kerosene oil can be very from origin to origin of bitumen. The rate analysis of the hot bitumen was shown in Table 4.

5.4 Cost Analysis

The graphical result of bitumen coverage with different proportioned of primer coverage area were shown in Figs. 4 and 5.

5.5 Discussion

Now to discuss how the Pre Package Polymer Modified Slurries work, what was the chemistry behind and what was the procedure of PPPMS? How polymers can modify a cementitious mortar to that extent that it becomes enormously waterproof and shows cent percent results in the on-field experiments on an area of more than 40000 ft^2. The main objective of porosity in cement mortar was due to the air entrained in it, and due to that porosity, the water can seeps through the RCC

Table 5 Comparison between Bitumen and PPPMS

Serial No.	Description	Bitumen	PPPMS
1	Rate per square feet (R.s)	26.8	14.44
2	Time saving	NOT	YES
3	workability	Difficult	Easy
4	Environmental Pollution	YES	NOT
5`	Economical	NOT	YES

slab and causes seepage. Moreover, oxygen, chlorides from salty water and moisture can move by the surface of the roof and spread to the RCC steel which was caused by erosion and consequent spelling. During hardening of cement mixture, the Pre Packaged Polymer Modified Slurry (PPPMS) was also developed porosity and microcracks by dispersed throughout the cement admixtures. Increased chemical resistance, the workability at a low water-cement ratio of the modified polymer was improved. The reductions of water were also improved durability and strength characteristics. Due to this, when determined the durability of the PPPMS system, porosity, and the pore size distributions were extremely important and, did not be considered as irrelevant. Pore size distribution and porosity were structure parameters than it had a direct effect on the water absorption of the cement paste. Moreover, the continuous flow of fluids in pores was also directed to the permeability. Permeability did not contribute the discontinuous pores in aggregates or in cement paste, on another hand, the total volume occupied by pores were expressed in percentage. Permeability was relatively high with high porosity and, with the pores was interconnected; equally, permeability was low, with pores of disconnected, irrespective if porosity was high. PPPMS of the pore structure system, maybe more than other distinctive, influences the performance and other behaviors of the materials. Therefore in this regards, the pore size distribution and porosity were important, due to their durability, strength, and permeability of the materials. The PPPMS method that was famous with its advanced durable performance and pore structure was consequently outstanding to be useful as waterproof, structure repair and floor topping materials.

6. Comparison between Bitumen and PPPMS

PPPMS were used on more than 50 houses for the same purpose as of bitumen. It was easy in application and required no considerable attention after its application as it almost absorbs in the surface of flat RCC roof. It has a negligible thickness and cannot be removed from the rcc slab once applied that can be the main reason why it has shown much more positive results than the bitumen. Following was a brief comparison of the cost to benefit ratio between Bitumen and PPPMS in Table 5.

7. Conclusions

Following conclusions may be drawn from the study reported in this paper.

• To conclude from this research that Bituminous Coatings were very difficult to apply and they were brittle in nature (on drying), due to which it was tempered by pedestrian working on the roof

thus causes seepage.

• Whereas, the Pre Packaged Polymer Modified Slurry (PPPMS) coatings were very easy to use, environment-friendly and flexible in nature. Due to this elasticity, the PPPMS cannot be treated off from the RCC slab's flat Surface, thus resists better against seepage.

• PPPMS were almost two times cheaper than the bituminous coatings when we compare the equal amount of area of application.

• In the broader aspect when we compare application easiness, performance behavior over time, cost-benefit analysis, the prepackaged polymer modified slurry coatings should be preferred over the bituminous coatings for waterproofing applications.

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