Polymer-Modified Mortars And Concrete Mix Design

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Polymer-modified Concrete (PMC) has also been called polymer-Portland cement-concrete (PPCC) and latex-modified concrete (LMC). It is defined as Portland cement and aggregate combined at the time of mixing with organic polymers that are dispersed or redispersed in water. This dispersion is called latex; the organic polymer is a substance composed of thousands of simple molecules combined into large molecules. The simple molecules are known as monomers, and the reaction that combine them is called polymerization. The polymer may be a homopolymer if it is made by the polymerization of one monomer, or a copolymer when two or more monomers are polymerized.

Of various polymer-modified mortar and concrete, latex-modified mortar and concrete have superior properties, such as high tensile and flexural strength, excellent adhesion, high waterproofness, high abrasion resistance and good chemical resistance, to ordinary cement mortar and concrete. Accordingly they are widely used in many specialized applications in which ordinary cement mortar and concrete have been employed to a lesser extent till now. In these applications, the latex-modified mortars are widely used rather than the latex-modified concrete from the viewpoint of a balance between their performance and cost.

Latex-modified concrete has been widely used in the field of patching, resurfacing or overlaying works for damaged bridge decks for the last 30 years, because of its ease of execution, excellent adhesion to the base concrete, high freeze-thaw durability and resistance to chloride penetration. Particularly in the U.S.A , hundreds of bridge decks have been restored with the latex-modified concrete since 1957.
Generally the modified mortar can be recommended for thickness of 30 mm or less, and the modified concrete for the thickness exceeding 30 mm. Floor/screeds/toppings upto 100 mm thick have been successfully used.

Latex-modified mortar and concrete should never to placed at temperature lower than 50C and higher than 300C. In application to larger areas, it is advisable to provide joints with a

width of about 15 mm at intervals of 3 to 4m. Generally polymer latex used as cement modifiers are not toxic, and are safe materials to handle. Consequently they require not special precautions.

Materials:

The materials used in latex-modified mortars and concrete are the same as those employed in ordinary Portland cement mortar and concrete.

Cements:

Ordinary Portland cement is widely used for latex-modified mortar and concrete. According to their applications, other Portland cement such as high-early-strength Portland cement, ultra high-early strength Portland cement, sulphate resisting Portland cement, moderate heat Portland cement and white Portland cement, blend cement and super high-early-strength cement are employed. Air-entraining cement should not be used because of air-entrainment due to latex addition.

Polymer Latexces:

In particular, the commercial latexces widely used in the world are styrene-butadiene rubber (SBR). It is estimated that over 9000 bridge decks alone in USA are protected with SBR Latex system, polychloroprene rubber (CR), polyacrylic ester (PAE), Poly (ethylene-vinyl accetate) (EVA) and poly (vinylidene chloride-vinyl chloride) (PVDC) copolymers. Most commercial polymer latexes for cement modifiers contain proper antifoaming agents, and can be generally used without addition of the antifoaming agents during mixing.

Powdered Emulsions:

At present commercially available powdered emulsions are VA/VeoVa, poly vinyl accetate-vinyl versatate and EVA, Poly-ethylene-vinl accetate. Generally the powdered emulsions are dry blended with cement and aggregates mixtures, followed by wet mixing with water. During the wet mixing, the powdered emulsions are re-emulsified, if necessary, an antifoaming agent is added to the wet mix. The curing of the modified system is similar to that of the latex-modified systems.

Aggregate:

Fine and coarse aggregates such as river sand and gravel, crushed sand and stone, silica sands and artificial lightweight aggregate recommended for ordinary cement mortar and concrete, are used for latex-modified mortar and concrete. For the purpose of corrosion resistance silica sand and siliceous crushed stones may also be used. The use of aggregates with excessive water content should be avoided because the required polymer-cement ratio will not be achieved.

Mix Proportioning:

The mix proportions of most latex-modified mortars are in the range of the cement; fine aggregate ratio = 1:2 to 1:3 (by weight), the polymer-cement ratio 5 to 20% and the water-cement ratio of 30 to 60%, depending on their required workability.

The mix proportions of most latex-modified concretes can not be easily determined in the same manner as those of latex-modified mortars, because of many factors are to be considered in the mix design. Normally the polymer-cement ratio of the latex-modified concrete ranges from 5 to 15%, and the water-cement ratio from 30 to 50%. A rational mix design system for the latex-modified concrete is described below:

This mix design is valid for the following conditions:

Types of materials used:

Types of cement	:	OP cement 53 Grade as per I.S : 12269-1987.
Types of aggregates	:	River sand of Zone II & III as per IS: 383-1970. It should not contain particles coarser than 2.5 mm.
River gravel	:	5-20 mm and 5-10 mm i.e 20 and 10 mm graded uncrushed aggregate as per IS: 383-1970. (both the above aggregates saturated and surface dry)
Polymer Latexes	:	commercial polymer latexes, irrespective polymer types (containing antifoamers)

Range of proportions in practical use:

Unit cement content (C)	:	From 250 to 400 kg/m^3 for 20 mm maximum size of aggregate
Polymer-cement ratio (P/C)	:	From 0.05 to 0.20 (5 to 20% by wt. of polymer with respect to cement)
Water-cement ratio (W/C)		From 0.30 to 0.50 (30 to 50% by wt. of water with respect to cement)
Slump		50 mm to 200 mm
Compressive Strength (fck)		From 200 to 600 kg/cm^2
Air (by Volume)		2% in 20 mm maximum size aggregate 3% in 10 mm maximum size aggregate

The procedure for determining the mix proportions of latex-modified concrete is carried out according to the following steps:

Step 1 : The required workability of fresh latex-modified concrete and the performance of hardened latex-modified concrete are determined corresponding to its field applications.

Step 2: The polymer-cement ratio (P/C) to give the required properties is determined on the basis of the information shown in catalogs and technical data by the manufacturers of polymer latexes for cement modifiers. Simultaneously the binder-void ratio to satisfy the required fck and P/C is determined by using an equation for compressive strength prediction.

Step 3: Prediction of compressive strength : (2 days moist 3 days wet and 10 days dry cured) – Regardless of polymer type, the compressive strength latex-modified concrete can be predicted at polymer-cement ratio of 5, 10, 15 and 20% by using binder-void ratio (q) as follows:

Polymer-cement ratio % fck
5 657 q – 40
10 595 q – 88
15 474 q – 63
20 423 q – 88
Step 4: The water-cement ratio (W/C) and the unit cement content (C) are estimated by introducing the determined q from table 1 and 2.

Step 5 : From cement quantity and W/C estimate the water content per m^3 of concrete for 20 mm maximum size of aggregate. For 10 mm maximum size of agagregate 10% water is to be increased.
The obtained water be adjusted after the first trial of slump, see Step. 12.
Step 6 : Work out the polymer quantity for the mix.

Step 7: Adjust the mixing water from the water in polymer.

Step 8: From the table 3 and 4 work out the density of latex-modified concrete.

Step 9: Work out the total aggregate content of the mix
Density – (Cement + Latex + Water)
Step 10: Work out sand content from table 5.

Step 11 : The coarse aggretate = total aggregates – sand

Step 12: Adjust the water content after actual slump trials for required workability. With the same W/C worked out the new cement content and then revised other mix proportions.

Example :
Calculate the quantity of the different materials required to design a mix for a latex-modified concrete for an anti-corrosive floor.
Cement : OPC 53 Grade
Aggregates: River sand of Zone II, specific gravity 2.65 and graded river gravel 5-20 mm specific gravity 2.65.
Cement modifier: SBR latex, total solids 47.2%, specific gravity of the total solids i.e polymer 1.01
Required slump : 100 mm
Required compressive strength (fck) = 400 kg/cm^2
Polymer-cement ratio (P/C): Corrosponding to the required chemical resistance 15% (based on the chemical resistance data given in the catalog. The latex is SBR.
Minimum Cement of the Mix 320 kg/m^3
Maximum Free W/C ratio = 0.45
Calculations:
Prediction of compressive strength : Substituting
fck = 400 kg/cm^2 and P/C = 15%
474 q – 63 = 400 hence,
q = (400 + 63)/474
q = 0.98
Estimation of W/C and cement content from table 1 and 2
W/C ratio = 43%
Cement = 330 kg/m^3
Estimation of water for the mix
330 x 0.43 = 142 kg/m^3
Estimation of Polymer
15/100 x 330 = 49.5 kg/m^3
As the specific gravities of the polymer and waer are 1.01 and 1.00 respectively.
Slump control factor = (49.5/101) + (142/1.00) = 191 kg/m^3
Since the total solids of the SBR latex are 47.2%, the required amount of latex is
49.5/0.472 = 105 kg/m^3
In which 55 kg is water,
Therefore net mixing of water = 142 – 55 = 87 kg/m^3

Density from table 4 = 2335 kg/m^3

aggregates = 2335 – 191 – 330 = 1814 kg/m^3

sand from table 5 for trial say 42%

sand = 1814 x 0.42 = 762 kg/m^3

aggregate = 1814 – 762 = 1052 kg/m^3

Therefore the required quantities of materials per m^3 of concrete on the basis of saturated and surface dry aggregates for the first trial in this example would be as given below:

Cement OPC 53 Grade = 330 kg/m^3

SBR Latex = 105 kg/m^3

Water = 87 kg/m^3

River Sand = 762 kg/m^3

River Gravel = 1052 kg/m^3

Density = 2336 kg/m^3

Table. 1

Binder-void ratio and W/C ratio with different P/C Ratio

Binder-void ratio q (by volume)	W/C ratio % P/C ratio %			
	5	**10**	**15**	**20**
0.7	45			
0.8	40	47		
0.9	35	42	47	50
1.0	30	37	42	45
1.1		32	37	40
1.2			32	35
1.3				30

Table. 2 Binder-void ratio and cement concrete with different P/C Ratio

Binder-void ratio ? (by volume)	Unit cement content kg/m^3			
	P/C ratio %			
	5	**10**	**15**	**20**
0.60	250			
0.65	275			
0.70	310			
0.75	340	250		
0.80	375	290		
0.85	400	325	250	
0.90		350	275	
0.95		380	315	
1.00		400	345	250
1.05			385	275
1.10			400	315
1.15				360
1.20				400

Note: 1. The cement content is for 20 mm maximum size of reiver gravel. For 10 mm maximum size of river gravel increased the cement content to 15% in each case.

2. Trial mixes should be made to check workability, density and strength, if need be the mix should be modified as er the required specifications.

Table. 3 Estimated wet density of fully compacted latex concrete (kg/m^3), maximum size of aggregate 10 mm

Slump control factor l/m^3	specific gravity of combined aggregates on saturated and surface dry basis				
	2.4	**2.5**	**2.6**	**2.7**	**2.8**
130	2227	2297	2367	2437	2507
140	2211	2281	2351	2421	2491
150	2195	2265	2335	2405	2475
160	2179	2249	2319	2389	2459
170	2163	2233	2303	2373	2443
180	2147	2217	2287	2357	2427
190	2131	2201	2271	2341	2411
200	2115	2185	2255	2325	2395
210	2099	2169	2239	2309	2379
220	2083	2153	2223	2293	2363
230	2067	2137	2207	2277	2347
240	2051	2121	2191	2261	2331

250	2035	2105	2175	2245	2315

The table is worked out for latex-concrete having cement content of 330 kg/m^3. For each 20 kg difference in cement content from 330 kg correct the weight per m^3 3 kg in the same direction.

Table. 4 Estimated wet density of fully compacted latex concrete (kg/m^3), maximum size of aggregate 20 mm

Slump control factor l/m^3	specific gravity of combined aggregates on saturated and surface dry basis				
	2.4	**2.5**	**2.6**	**2.7**	**2.8**
120	2273	2343	2413	2483	2553
130	2257	2327	2397	2467	2537
140	2241	2311	2381	2451	2521
150	2225	2295	2365	2435	2505
160	2209	2279	2349	2419	2489
170	2193	2263	2333	2403	2473
180	2177	2247	2317	2387	2457
190	2161	2241	2301	2371	2441
200	2145	2215	2285	2355	2425
210	2129	2199	2269	2339	2409
220	2113	2183	2253	2323	2393

230	2097	2167	2237	2307	2377

The table is worked out for latex-concrete having cement content of 330 kg/m^3. For each 20 kg difference in cement content from 330 kg correct the weight per m^3 3 kg in the same direction.

Table. 5 Proportion of sand (percent) with 10 mm and 20 mm maximum size of aggregate, slump 50 mm – 200 mm

Zone of sand	Free W/C ratio	10 mm aggregate	20 mm aggregate
II	0.3	44-54	35-44
	0.4	46-57	37-46
	0.5	47-59	39-48
III	0.3	37-44	30-35
	0.4	38-46	31-37
	0.5	40-47	33-39

Table 6 ACI Guidelines for Mix Proportions of SBR-Modified Concrete Ovedrlays

Unit cement content, minimum	390 kg/m^3
Unit SBR Latex content, minimum	121 kg/m^3
Unit water content, maximum	94 kg/m^3
Air content, maximum (ASTM C 2311)	6.5%
Slump range	7.5 – 20.5mm
Overlay thickness, minimum	2.5 cm

Coarse aggregate size, maximum	No.8
Fine aggregate- Aggregate ratio	55-70 wt %
Cement: Fine aggregate : Coarse aggregate (Aggregate assumed saturated, surface dry)	1.0 : 2.8 : 1.7 (weight ratio)

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