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## Selection of polymers for repair and rehabilitation of RC structures

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*Polymer being the costliest input in any repair and rehabilitation job, the selection of an appropriate brand assumes importance. The author has done laboratory testing of acrylic and SBR polymers from five leading manufacturers and the results obtained are compared with those claimed by the manufacturers in their data sheets/brochures. A large variation was observed between the actual test results and those furnished by the manufacturers. The author suggests certain remedies to overcome this problem.*

Due to the rapid deterioration of concrete structures, more and more repair and rehabilitation works are being taken up. For such work, the procedures followed in general practice include the following:

- removal of loose/damaged concrete
- preparation of substrate including removal of rust on reinforcement and application of corrosion-resistant coating on the same
- application of bond coat to the substrate
- application of polymer-modified mortar for patch repair repair work, and

- application of coating to the repaired surface.

Most of the repair works involves use of polymer for bond coat and polymer-modified mortar.

Most widely used polymers for application in cementitious repair work are urethane, acrylic and modified acrylics, poly vinyl acetates, styrene butadiene rubber, chloro-prene rubber (CR) polyacrylic ester (PAE), poly ethylene vinyl acetate (EVA or VAE), poly styrene acrylic ester (SAE). Poly vinyl acetate latex, polyvinylidene chloride and poly vinyl chloride latex are generally not recommended as cement modifiers because of poor resistance to chloride ion liberation<sup>2</sup>.

Using polymer latex in cementitious mixture improves a host of properties of such as enhanced resistance to crack propagation, increased tensile, flexural and bond strength resistance to alkalis and chlorides, abrasion resistance, impermeability to chloride ions, moisture, carbon-dioxide and oxygen, etc.

Polymer is a major and the costliest component in the PMM. Further, the final properties of the PMM are very much dependent upon the physical and chemical properties of the polymer itself. It is therefore highly essential that the selection of the polymer is done with

due care and with prior laboratory testing. This is usually avoided and there is a tendency amongst engineers to wholly rely on the test certificates or brochures given by the manufacturers.

### Laboratory testing of polymers

There are a number of construction chemical manufacturers in the market and several others are entering this field with or without foreign collaborations. They supply a long list of construction chemicals with technical brochures which are mostly commercial in nature. The brochures contain brief description of materials, mixture proportions, application instructions and advantages of using these products. Some manufacturers mention the test results achievable with the use of their polymer products.

As per Table 1, there are as many as 18 properties which need to be checked before recommending a particular polymer brand for a project. Most of the manufacturers/suppliers do not give test results for all these properties, even when demanded, as they might not have got their products tested for all these properties. Some do provide the test results; but the tests are invariably carried out by the parent company based abroad. Also the client, whether government department or a private consultant, does not have

**Table 1 : Test method for performance evaluation<sup>1</sup>**

No.	Performance requirement	Test standards
1	Density	ISO 6276, BS 1881:PART- 114; ASTM C 905
2	Workability	ISO 4109;VEBE ISO 4110;Flow Table ISO 9812
3	Compressive strength	ISO4012 Concrete; BS 6319 PART 2 PC Mortar; ASTM C 579-91, ASTM C39; ASTM C 109,DIN 1164
4	Elastic modulus	ASTM C 78-94 ; ISO 6789 ; RILEM NDT 2
4	Direct tensile strength	ASTM C 307-94;ASTM E 149-76; RILEM 13 MR
5	Flexural strength	ASTM C 78-94;ASTM C 190; DIN 1164, BS6319; Part 4
6	Splitting tensile strength	ASTM C 496-90 ; BS 1881
7	Water absorption	ASTM C 413—94; BS 1881:Part 122
8	Permeability	DIN 1048
9	Abrasion resistance	ASTM C 418-90; DIN 53754
10	Direct shear	ACI SP- 89
11	Slant shear test	ASTM C 882 -91; ASTM C 1042-91,B S 6319 Part IV
12	Thermal compatibility	ASTM C 884-89
13	Dimensional stability	ASTM C 596, C827;PC Mortars, BS 6319 Part 12, German Tough Test, Ring Test (Restrained), SPS – Test
14	Gas permeability	Test derived From Nord test- By UKTG
15	Durability/compatibility	RILEM TC 52-RAC NO.6
16	Resistance to carbonation	RILEM CPC-18
17	Chloride ion diffusion	ASTM C 1202 -1995
18	Linear coefficient of shrinkage	ASTM D 2566

enough time and resources to get these tests done for various brands available in the market before recommending a particular brand for his project. The designer therefore has to be very careful in the selection of the suitable polymer with required characteristics for a particular project.

To understand the properties of polymer-modified mortars actually achievable in laboratory, the acrylic and SBR polymers from five different manufacturers were collected and tested for solid content, compressive strength, splitting tensile strength, flexural strength, and direct shear bond strength. The PMM was prepared in the proportion 1:3, that is, 1 part cement to 3 parts standard sand, modified with the polymer dose as per the recommendations of the various manufacturers. Tests were carried out to find out properties at 3, 7 and 28 days. For compressive strength and splitting tensile strengths, mortar cube mould of 70.6 mm size were used. For flexural strength, PMM test specimens of size 280 mm × 55 mm × 25 mm were used with centre point loading. For direct shear bond strength, there are no standard test procedures available. The PMM patch having dimensions 50 mm × 50 mm × 12.5 mm was centrally cast and cured on a 150 mm × 150 mm × 150 mm, unmodified concrete base piece. Load was applied vertically very close to the bonded interface to avoid bending stresses. The shear bond

strength was calculated by dividing the load at failure by the interfacial area of the patch. The test samples were moist cured for 3 days and subsequently air cured in the laboratory environment. The test results obtained at 28 days are given in Tables 2 and 3 for acrylic polymer and SBR polymers, respectively.

### Main observations

#### Acrylic polymer

The following major observations were made during the tests.

- (i) Most manufacturers do not mention the properties of the

polymer such as solid content and strength.

- (ii) For manufacturers A and B, comparison could not be made as strengths were not mentioned in the product brochure.
- (iii) For manufacturer C, the first batch of acrylic polymer received was tested at 16 percent and 20 percent dosages but strength obtained was about 50 percent of the claimed strength. So a fresh sample was obtained directly from manufacturer and tested. At the polymer dosage of 20 percent of cement content, satisfactory strengths meeting brochure strength were obtained except the shear bond strength. The claimed shear bond strength was 20 N/mm<sup>2</sup> which was approximately converted into direct shear bond strength value of 5.5 N/mm<sup>2</sup> by using the relation given by Sabnis *et al*<sup>3</sup>. Direct shear bond strength obtained in laboratory was 2.64 N/mm<sup>2</sup> which was 48 percent of the claimed strength.
- (iv) For manufacturer D, the compressive and flexural strengths actually obtained were 29.6 N/mm<sup>2</sup> and 5.35 N/mm<sup>2</sup> which were 53.81 percent and 48.63 percent of the claimed strengths of 55 N/mm<sup>2</sup> and 11 N/mm<sup>2</sup>, respectively. Data on solid content and tensile strength were not provided by the manufacturer.

**Table 2: Test results of PMM (using acrylic polymer)**

No.	Strength parameter	Brand- A		Brand- B		Brand- C		Brand- D		Brand- E	
		Br	T	Br	T	Br	T	Br	T	Br	T
1	Solid content, percent	Not given	43.7	Not given	41.5	Not given	51.1	Not given	30.30	Not given	47.7
2	Dose, percent	20	20	33	33	16-20	20	15	15	16-20	20
3	Compressive strength, N/mm <sup>2</sup>	Not given	21.00	Not given	24.00	40.00	41.46	55.00	29.6	33.32	29.6
4	Tensile strength, N/mm <sup>2</sup>	Not given	3.21	Not given	3.84	4.5	4.25	Not given	3.32	Not given	4.46
5	Flexural strength, N/mm <sup>2</sup>	Not given	7.32	Not given	7.32	11.00	12.87	11.00	5.35	8.82	7.54
6	Shear bond strength, N/mm <sup>2</sup>	Not given	1.79	2 × bond strength of cement	3.46	20 SSB 5.55 DSB	2.64 3.3 (DSB)	1.9 (UTB)	1.05	SSB=7.84 at 14 days, 2.17 (DSB)	1.94

Note: Br: As per brochure, T: As per testing SSB: Slant shear bond, UTB: Uni-axial tensile bond, DSB: Direct shear bond

**Table 3: Test results of PMM (using SBR polymer)**

No.	Strength parameter	Brand-A		Brand-B		Brand-C		Brand-D		Brand-E	
		Br	T	Br	T	Br	T	Br	T	Br	T
1	Solid content, percent	Not given	47.5	Not given	51.1	NG given	30.6	Not given	30.6	Not given	44
2	Dosage, percent	20	20	20	20	20	20	20	20	20	20
3	Compressive strength, N/mm <sup>2</sup>	Not given	32.8	45-50	46.2	24.0	14.2	57	14.2	31.3	38.80
4	Tensile strength, N/mm <sup>2</sup>	Not given	4.57	6.50	4.06	3.5	2.13	Not given	2.13	3.23 at 7 days	3.94 at 7 days 4.67
5	Flexural strength, N/mm <sup>2</sup>	Not given	6.83	13.00	11.42	6.5	2.74	11.9	2.74	14.01 at 7 days	7.16 at 7 days 10.5
6	Shear bond strength, N/mm <sup>2</sup>	Not given	2.73	Not given	1.68	Not given	0.56	2.5 (UTB) 4.38 (DSB)	0.56	2.39	1.68

Note: Br: As per Brochure, T: As per testing

The claimed uniaxial tensile bond strength was 1.9 N/mm<sup>2</sup> which was equivalent to 3.33 N/mm<sup>2</sup> in direct shear bond at 28 days. The obtained strength was 1.05 N/mm<sup>2</sup> which was just 31.53 percent of claimed strength.

- (v) For manufacturer E, the compressive, and flexural strengths obtained were about 88.83 percent and 85.48 percent of the claimed strengths of 33.32 N/mm<sup>2</sup> and 8.82 N/mm<sup>2</sup>, respectively. The claimed slant shear bond strength was 7.84 N/mm<sup>2</sup> at 14 days which was equivalent to 2.17 N/mm<sup>2</sup> in direct shear bond. The shear bond strength value obtained at 28 days of curing was 1.94 N/mm<sup>2</sup> which was 89.40 percent of the claimed strength.

### SBR polymer

Regarding SBR polymer, the following observations were made.

- (i) Manufacturer A, did not give any data in its product brochure regarding solid content or strengths achievable with the use of its polymer. Possibly, the manufacturer was not involved in the manufacturer of SBR latex. Hence, sample could not be obtained for this brand.
- (ii) Manufacturer B, provided compressive, tensile and flexural strengths respectively as 45-50 N/mm<sup>2</sup>, 6.50 N/mm<sup>2</sup> and

13.00 N/mm<sup>2</sup> at 20 percent dosage of polymer. The corresponding strengths achieved in the laboratory were 32.8 N/mm<sup>2</sup>, 4.57 N/mm<sup>2</sup> and 6.83 N/mm<sup>2</sup> which were 69.05 percent, 70.30 percent and 52.53 percent, respectively of the claimed strengths. The shear bond strength was not given in the brochure but its value was tested out to be 2.73 N/mm<sup>2</sup> which was quite satisfactory.

- (iii) The SBR polymer from manufacturer C, has yielded compressive strength, tensile and flexural strengths as 46.2 N/mm<sup>2</sup>, 4.06 N/mm<sup>2</sup> and 11.42 N/mm<sup>2</sup> against claimed strengths of 24.00 N/mm<sup>2</sup>, 3.5 N/mm<sup>2</sup> and 6.5 N/mm<sup>2</sup> respectively. The obtained compressive, tensile and flexural strengths were 92.5 percent, 16 percent and 75.69 percent, respectively above the corresponding claimed strengths. Shear bond strength value was not given in brochure, but on testing was found to be 1.68 N/mm<sup>2</sup>.
- (iv) The SBR polymer from manufacturer D yielded strengths much lower than the claimed strengths. Solid content found was 30.60 on testing .
- (v) The SBR polymer from manufacturer E with solid content of 44 percent yielded compressive strength 38.80 N/mm<sup>2</sup> against

claimed strength of 31.3 N/mm<sup>2</sup> which was 23.96 percent, more. The manufacturer claimed tensile strength of 3.23 N/mm<sup>2</sup> at 7 days. According to the laboratory test, the 7-day strength was 3.94 N/mm<sup>2</sup> which was 21.98 percent more. The 28-day strength obtained was 4.67 N/mm<sup>2</sup>. Similarly, the 7-day flexural strength obtained was only 7.16 N/mm<sup>2</sup> against claimed strength of 14.01 N/mm<sup>2</sup> which was 48.89 percent less. Flexural strength obtained at 28 days was 10.5 N/mm<sup>2</sup>. Shear bond strength obtained was 1.68 N/mm<sup>2</sup>.

It is obvious from the evaluation that the buyer/engineer is provided with limited information which at times is misleading too. In the product data sheets, properties favourable to the material were reported. Such information does not enable the engineer to correctly select the material for durable repair work. The engineer may not have time to test the polymers from different manufacturers to confirm the strengths actually achievable after a curing period of 28 days.

Some of the reasons for deviations from claimed results are given below.

- (i) Some manufacturers may simply be copying the test results from their collaborator's product data sheets without getting similar tests done locally with the local products.
- (ii) The manufacturer's product may be genuine but the dealers/agents may adulterate the product without the knowledge of the manufacturer.
- (iii) Some manufacturers may supply tailor-made products initially but may water down the quality later.
- (iv) Some of the tests are non-standard, so the test results from different laboratories carried out with different procedures may be different, thus making the evaluation difficult for the users.
- (v) It was also found that coverage of bond coats prepared with the polymer as per manufacturers' specifications was less than what

was claimed by manufacturers. If the contractor is paid as per quantity of polymer brought at site, large deviations will result if work is carried out with desired quality standards. On the other hand, if mode of payment is by area of bond coat applied, the contractor shall compromise with the quality of the bond coat to avoid loss due to less coverage obtained at site. Such situations will result in disputes between the contractor and quality conscious engineer.

Due to the discrepancy between the claimed strengths and laboratory test results, projects suffer either in quality/durability or there is time and cost overrun. In repair and rehabilitation projects of private companies, the clients generally advise the contractor to complete the work with minimum possible time due to their own constraints. As a result, contractor may not have sufficient time for material testing and may commit on giving false guarantees for durable repairs which may end in litigations. Similarly, in certain contracts, time is the most important factor and agency has to complete the work within the scheduled completion date failing which the clause of compensation for delay comes into force.

Timely completion of the repair projects with appropriate quality is possible only if polymers or any construction chemicals that is selected while preparation of tenders yield the same results as per specifications based on the product data sheets. Otherwise valuable time is lost in repeated laboratory testing while approving the polymers which may delay the completion of the project. Also, during progress of the work, quality of construction chemicals brought at site need to be consistent so that time is saved in repeated laboratory testing. This is more important because there are no standards / codes on this subject.

### Conclusions

The following conclusions can be drawn from the above study.

- (i) Manufacturers must completely provide data on physical, chemical

and mechanical properties as realistically obtained with standard testing procedures. This standard data sheet protocol should include data on material composition and limitation of the material under specific application and service conditions. Since the selection of the best repair material for given application and exposure condition is a necessity, based on the optimum combination of the several material properties, material data sheets must become reliable sources for standardised information on these properties. This is most important since there are no authoritative and formalised codes of practice and accepted standards for performance criteria of the various polymers for concrete repairs.

- (ii) The product datasheet should also mention application methodology, curing requirements, materials requirements for various uses, coverage rates etc.
- (iii) It was observed that to test a given property of a polymer, ASTM, British standards, or other international standards can be followed. The results of these tests are likely to be different for the same material tested which makes the situation difficult to select a suitable brand of a polymer. Therefore, it is important that manufacturers follow both system of testing and provide results in their brochures so that selection is easy.
- (iv) A difficult situation may arise when different manufacturers provide complete data about their brand's properties but it may not be possible to select the best brand as some strengths/ properties of one brand may be better than the others but may have inadequate values for other important parameters. In such a situation it is required to judge the parameters which are most important for a particular job.
- (v) Polymer is the costliest material. So cost incurred on purchase and use of these chemicals must

produce good results which is possible only if one is seriously involved with the proper selection of the material. All construction chemicals should be thoroughly tested in standard laboratories before approval. This is very important considering the lack of codes/ standards on the subject. Every batch of the material brought at site should be tested before its use.

### Recommendations

Actually speaking, the manufacturers of chemicals/polymers could be the best friend of engineers/consultants. There should be good co-ordination and understanding between them with the sole objective of getting the best quality repair work executed within the shortest possible time and with the lowest possible cost. The commitment to quality needs to be from both sides.

In absence of standard codes/specifications, its is highly essential that some useful guidelines for repair works may be formulated with the co-operation and initiative from construction chemical manufacturers. Possibly, some of the professional bodies can also lend a helping hand for this purpose.

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