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An investigation on epoxy and polyester resin mortars as a jointing material

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An investigation on epoxy and polyester resin mortars as a jointing material

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SUMMARY

The Norwegian Building Research Institute has undertaken as a research project a study of the possibility of joining prefabricated concrete building components by means of synthetic resins. The first part of the program is a study of different mortars from which we hope to be able to evaluate their structural properties. This paper deals with an investigation on 45 different mixes of resin mortars. Three epoxies and two polyesters were used as binder in varying proportions in the mix—15, 20 and 25 % by wt. Three types of aggregates were used and of the 9—25 mm × 25 × 170 mm test specimen cast, 3 were cured at 20 °C and either 30, 65 or 85 % RH for 7 days. Bending-, compressive- and splitting tensile strength were determined for all the test specimens. Using each mix, concrete cylinders, beams, and cubes were jointed together with a 5 mm joint. The test specimens were cured 7 days at 20 °C and 65 % RH and then tested for bond-, bending-and shear strength. To test the bond between the different mixes and reinforcing steel, mortar was filled in a steel pipe and deformed steel bars 20 mm were pushed into the pipe butting together 10 cm from the end of the pipe. When the mortar had cured for 7 days at 20 °C and 65 % RH the strength of the joint was tested.

RÉSUMÉ

L'Institut de Recherche du Bâtiment de Norvège a mis en route un projet de recherches ayant pour but l'étude de la possibilité d'assembler les éléments de construction en béton au moyen de résines synthétiques. La première partie de ce programme consiste en l'étude des différents mortiers de résine avec l'espoir d'en déterminer les propriétés structurales. Ce rapport rend compte d'une recherche sur 45 mortiers de résine de compositions différentes : trois époxydes et deux polyesters ont été utilisés comme liants en différentes proportions dans le mélange 15, 20 et 25 % en poids. Trois types d'agrégats ont servi et 3 des 9 éprouvettes coulées aux dimensions de 25 × 25 × 170 mm ont été conservées à 20 °C et à différentes humidités relatives : 30, 65 ou 85 % durant 7 jours. On a déterminé la résistance en traction par flexion, compression et fendage de toutes les éprouvettes d'essai. En faisant usage de chaque mélange, les cylindres, prismes et cubes de béton ont été assemblés avec un joint de 5 mm. Les éprouvettes ont été conservées durant 7 jours à 20 °C et à 65 °C HR, puis soumises aux essais d'adhérence, flexion et cisaillement. Afin d'éprouver l'adhérence entre les différents mélanges et l'acier des armatures, on a rempli un tuyau d'acier avec le mortier et des barres de haute adhérence de φ 20 mm y ont été enfoncées, abuttant ensemble à 10 cm de l'extrémité du tuyau. Après la conservation durant 7 jours à 20 °C et 65 °C HR, on a éprouvé la résistance du joint.

INTRODUCTION

The Norwegian Building Research Institute began its research with synthetic resins in 1965 when it was felt that resin mortars would be a highly promising material for joining precast concrete building components. The research was planned to be carried out in three steps:

1) To make a literature study on resin mortars and preliminary tests.

2) To design different joints and make a structural and economic evaluation of their feasibility.

3) To test joints in full scale.

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The necessity of working with fine dimensional tolerances for joints in concrete components would limit the applicability of a jointing method; consequently, it was decided to use a resin with a filler, preferably a mineral aggregate, that would allow reasonable joint thicknesses. The criteria of curing at low temperatures, and high strength, of mortar were decisive for the intended application of the mortar.

By comparing physical and mechanical properties of resins [1] and resin mortars [2] epoxy-, unsaturated polyester- and furan resins were considered to be the most promising binders for high-strength resin mortars. As it was difficult to obtain a furan resin commercially this type of resin was excluded from the testing program.

Choosing the most suitable epoxy- and polyester resin would be a very difficult task considering the wide variety of chemical compounds making up each system of resins and complicated by the numerous additives and curing compounds which are employed. To avoid time-consuming pitfalls it was decided to use resins and curing compounds recommended for jointing of concrete components by resin manufacturers. The testing program has been met with interest and the Institute has received valuable advice from its suppliers of resins—CIBA representative in Norway O. Pers-Pleym & Co., Shell Chemical Norway, and a Norwegian manufacturer of polyesters, Denofa-Lilleborg A/S.

In the preliminary tests it was important to establish testing methods, and to test a fairly large number of mortars for comparison of strength values in later tests. To obtain the best strength correlation with mortar thicknesses used in joints it was considered advantageous to use small test specimens. For the same reason the Nordic countries are using small test specimens for testing the strength of conventional mortars. Therefore, the same size of test specimens and testing methods as described for conventional mortars in [3] were adopted. To compare mortar strength with joint strength, testing of joints was included. The types of joints tested were concrete specimens bonded together with a 5 mm mortar joint, and reinforcing steel bars jointed in a steel pipe filled with mortar.

Resin mortars with binder 2 and 3 were tested by engineering students at The Technical University of Norway, Trondheim.

1. MATERIALS, CURING CONDITIONS, TEST SPECIMENS, AND TESTING APPARATUS

1.1. Materials.

1.1.1. Resins and Hardeners.

1.1.2. Aggregates.

No. 1: Mortar sand according to Norwegian Standard NS 422 A.

No. 2: Quartz flour — 30 % by wt; Quartz sand (0,8-1,2 mm) — 70 % by wt.

No. 3: Belgian normsand according to Norwegian Standard NS 425.

1.1.3. Concrete.

The 28-day compressive cube strength of concrete was 300-350 kp/cm^2.

1.1.4. Reinforcing Steel.

The bars were deformed steel bars with nominal diameter 20 mm and yield point 40 kp/mm^2.

1.2. Curing conditions.

No. 1: 7 days at 20 °C — 30 % ± 5 R.H.

No. 2: 7 days at 20 °C — 65 % R.H.

No. 3: 7 days at 20 °C — 85 % ± 5 R.H.

1.3. Test specimens.

The mortar was mixed in a 0.013 m^3 pan mixer, each batch consisting of 4, 000 grams and with the following mixing ratios in % by wt:

No. 1: Binder 15 % — Aggregate 85 %.

No. 2: Binder 20 % — Aggregate 80 %.

No. 3: Binder 25 % — Aggregate 75 %.

9-25 mm × 25 mm × 170 mm mortar prisms from each mix were cast in metal forms holding three prisms. One form was placed immediately in each of the curing conditions, and forms were stripped after one day.

6-100 mm φ × 50 mm concrete cylinders were jointed in pairs. 2-40 mm × 100 mm × 250 mm concrete beams, reinforced with one 5 mm steel wire, were jointed in a plywood form. 3-70.7 mm concrete

Binder no.	Resin	Hardener	% by wt	Viscosity at 22 °C, cps
1. (Epoxy, CIBA)	× 183/2313	× 157/2273	85 15	440
2. (Epoxy, SHELL)	Epikote 816	Versamid 140	54 46	6,450
3. (Polyester, DENOFA)	Delipol z-5 Delipol 70	Peroxyd	78 20 2	1,100
4. (Polyester, DENOFA)	x-40	Peroxyd Cobalt naphtenate 6 % in solution	99.2 0.5 0.3	6,100
5. (Epoxy, SHELL)	Epikote 816	Versamid 140 N.A.E.P. Phenol	59 26.5 10.5 4	1,240

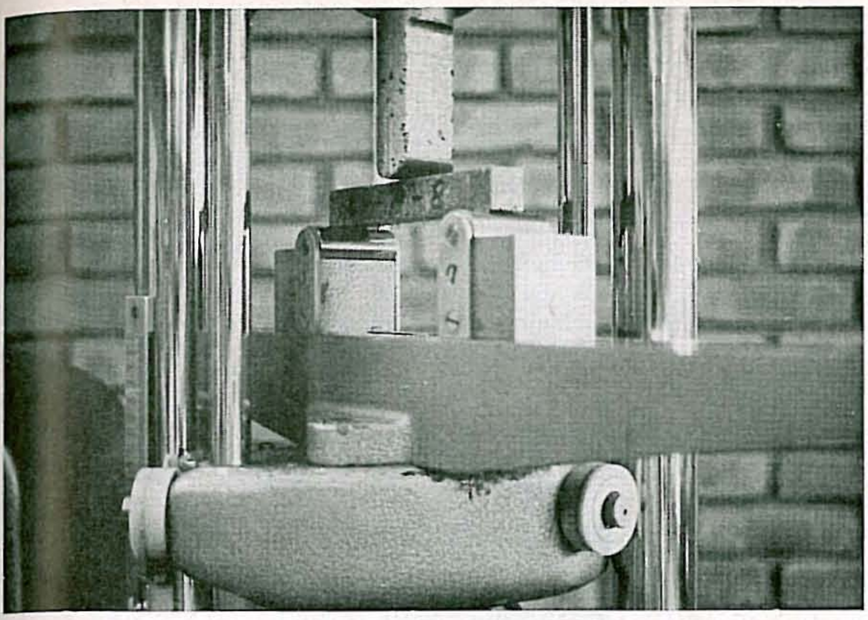


FIG. 1. — The bending test.

cubes were also jointed in a plywood form. Concrete surfaces to be jointed were wire brushed. Joint thicknesses were approximately 5 mm. All the specimens were placed in curing condition no. 2, and forms were stripped after one day.

One deformed steel bar 20 mm φ was held vertically in a rack, a 200 mm steel pipe with 46 mm outside and 28 mm inside diameter was positioned in a slot in the rack with the bar entering 100 mm into the pipe. Then, the pipe was filled with mortar and a second bar 20 mm φ pushed into the mortar until it butted against the first one. For stiff mixes difficulties were experienced pushing the second bar into the pipe and in most cases it was inserted a distance of only 50 mm to 80 mm. Steel surfaces to be in contact with mortar were wiped off with trichlorethylene. Specimens were placed in curing condition no. 2.

1.4. Testing apparatus.

Viscosity of the binders was measured with a Brookfield Synchro-lectric Viscometer Model RVF. The bending tests and the tensile splitting strength test were performed in a 2,000 kp Zwick testing machine.

A 300 ton Dennison testing machine was used for the compression and the shear tests. The bond tests were carried out in a tensile testing frame loaded hydraulically. The applied force was registered electrically.

Testing machines used in Trondheim were of standard type and accuracy but differed from the ones described.

2. TEST PROCEDURE

The only test specimens requiring special preparation before testing were the concrete cylinders; to apply a tensile load, 35 mm steel plates were glued with epoxy to each end of the cylinders. The rate of loading was approximately 30 seconds to failure in all tests.

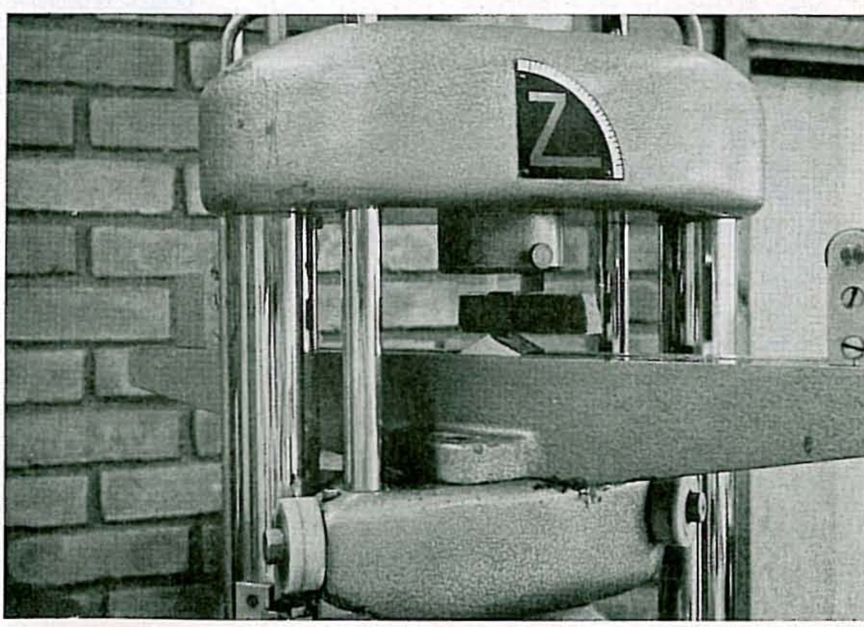


FIG 2. — The tensile test.

2.1. Mortar prisms.

The prisms were first broken in bending and then the two halves were used for the compression and the tensile splitting strength test. In the bending test the prisms were freely supported on rollers and spanned 150 mm. They were loaded with a linear load in the middle of the span until failure (see figure 1). One half of each broken prism was compressed until failure between two steel strips with contact area 1.5 mm × 25 mm (see figure 2). The second half was tested in compression between two steel pieces with contact area 25 mm × 25 mm.

2.2. Concrete test specimens.

Beams were freely supported on rollers and spanned 450 mm. They were tested with four-point loading and broken in bending. The three cubes jointed together were supported on the outside of the joints and loaded in shear with a linear load on the inside of the joints. Cylinders jointed together were tested in direct tension (see figure 3).

2.3. Reinforcing steel joints.

The bond strength of joints was tested in direct tension as shown in figure 4.

3. TEST RESULTS

3.1. Test data.

Test data are listed in *tables 1 and 2*.

3.2. Fracture description.

Fractures in the tensile splitting strength tests looked like typical tension failures and despite the small contact loading areas there were no indications of crushing of the surfaces where the loads were applied.

Most of the failures in the concrete beams occurred in the first 3 mm of the concrete in the concrete to mortar interface. Some failures were in the interface and some entirely in the concrete.

For weak mortars the failures in the shear tests were in the concrete to mortar interface. Cubes jointed with a strong mortar failed either in bending of the middle cube or in the first 3 mm of the concrete surfaces in the joint.

Concrete cylinders loaded in tension either opened up in the joint, fractured in the first 3 mm of one of the 4 concrete surfaces, or for a few specimens failed in the concrete.

Pull-out tests with deformed bars embedded in strong mortars showed that end slip began above the yield point of the steel. Bars either embedded in pipes not completely filled with mortar or in weak mortar were pulled out without reaching the yield point of the steel.

3.3. Error considerations.

Analysing the test results for the mortar prisms, one must take into consideration that it was possible to compact mortars with low workability when casting. The prisms thus yielded higher strength values for the mortar with low workability than what will be reached in field use of the mortar.

If the mortar surfaces were crushed under the applied linear loads in the tensile splitting strength test this would decrease the failure load. The values for the tensile splitting stresses shown in table 1 (computed using formula in [2]) were twice the value of the computed stresses using the ordinary stress formula [6]. By comparing these last values with the flexural bending stresses, it was indicated that the surface was crushed.

The joint in the concrete cube test were in combined bending and shear, yielding a shear-value too low for the joint. The computed shear stresses shown in table 2 are not true shear values.

Irregularities in alignment of the embedded bars would increase the failure load in the pull-out test.

FIG. 3. — The bond test.

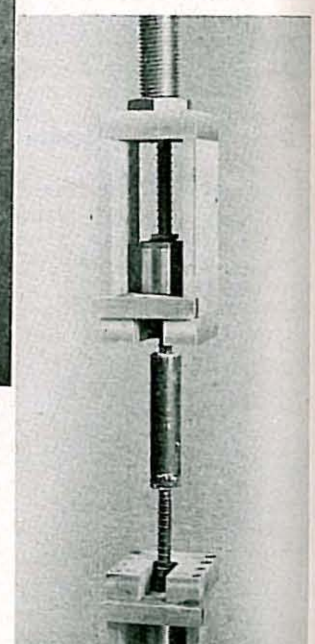


FIG. 4. — The pull-out test.

TABLE 1

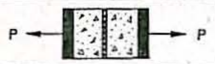
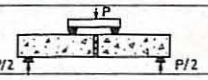
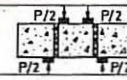
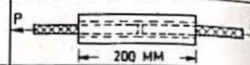
TEST DATA FOR 25 MM x 25 MM x 170 MM MORTAR PRISMS

TEST METHOD AND STRESS FORMULA				150 MM; P; P/2; P/2		$\sigma = \frac{P/2 \cdot 15/2}{\frac{1}{6} \cdot 2,5^3}$			P; P		$\sigma = \frac{P}{\pi \cdot \frac{2,5^2}{4}}$			P; P		$\sigma = \frac{P}{2,5^2}$		
				TENSILE BENDING STRENGTH, KP/CM²					TENSILE SPLITTING STRENGTH, KP/CM²					COMPRESSIVE STRENGTH, KP/CM²				
				CURING CONDITION				MIN.	CURING CONDITION				MIN.	CURING CONDITION				MIN.
MIX NO.	BINDER	AGGREGATE	MIXING RATIO	1	2	3	AVERAGE	MAX. VALUE	1	2	3	AVERAGE	MAX. VALUE	1	2	3	AVERAGE	MAX. VALUE
1			1	319	319	299	312	285 / 332	272	276	273	274	267 / 287	173	1168	1170	1170	1140 / 1230
2		1	2	298	273	332	301	204 / 355	277	274	271	274	265 / 289	1215	1227	1155	1199	1120 / 1250
3			3	267	308	300	292	249 / 318	244	260	253	252	235 / 270	1080	977	1147	1065	960 / 1170
4			1	362	348	336	349	301 / 379	240	262	242	248	214 / 278	860	908	827	865	720 / 1090
5	1	2	2	362	369	350	360	328 / 395	214	263	186	221	155 / 282	1157	1207	902	1089	850 / 1220
6			3	303	370	358	344	288 / 395	196	242	251	230	169 / 276	1063	1100	1110	1091	1010 / 1170
7			1	295	316	318	310	285 / 325	224	279	259	254	155 / 289	1030	1147	1087	1088	990 / 1170
8		3	2	304	354	347	335	295 / 381	237	288	253	259	188 / 289	1090	1137	1175	1134	1070 / 1220
9			3	283	279	318	293	269 / 331	224	236	257	239	212 / 273	940	1047	1067	1018	865 / 1070
10			1	290	320	325	312	285 / 335	152	168	162	161	150 / 168	643	668	629	647	604 / 702
11		1	2	349	346	309	335	272 / 380	176	190	160	176	152 / 194	714	654	593	654	535 / 742
12			3	220	214	211	215	186 / 249	92	106	102	100	88 / 108	348	327	321	332	298 / 378
13			1	234	232	169	212	153 / 284	144	166	138	150	122 / 182	621	360	535	505	306 / 722
14	2	2	2	367	270	315	317	233 / 394	156	150	182	164	144 / 190	602	558	628	596	550 / 670
15			3	376	348	394	373	315 / 418	162	182	176	173	152 / 188	620	538	605	588	306 / 722
16			1	327	339	324	330	300 / 360	172	174	176	174	164 / 186	700	591	600	630	566 / 734
17		3	2	316	324	300	313	209 / 330	142	166	154	151	132 / 168	527	540	420	496	344 / 570
18			3	267	262	269	266	208 / 306	112	124	134	124	108 / 136	460	523	463	482	450 / 734
19			1	239	219	211	223	190 / 258	178	160	138	158	128 / 182	785	736	740	754	688 / 838
20		1	2	208	194	198	200	165 / 237	136	126	136	132	120 / 152	644	696	675	672	560 / 753
21			3	328	318	319	322	290 / 338	200	192	180	190	174 / 204	876	864	841	860	829 / 885
22			1	176	148	154	159	136 / 189	96	100	86	94	80 / 100	372	401	429	401	361 / 452
23	3	2	2	266	258	326	283	244 / 352	162	150	156	156	144 / 180	578	604	609	597	533 / 640
24			3	287	301	291	293	273 / 305	158	160	170	162	156 / 176	719	706	729	718	693 / 733
25			1	188	228	200	205	178 / 231	118	124	96	112	90 / 134	619	588	597	601	541 / 634
26		3	2	254	250	262	255	234 / 274	150	142	148	146	130 / 152	657	672	640	657	634 / 676
27			3	305	309	332	315	250 / 379	172	164	178	171	152 / 192	698	835	810	781	642 / 855
28			1		260	232		229 / 270		234	217		211 / 236		992	970		960 / 1040
29		1	2	276	251	216	248	206 / 289	227	212	294	211	185 / 236	955	943	822	907	800 / 990
30			3	250	238	247	245	220 / 255	215	205	213	211	193 / 234	928	970	928	942	895 / 990
31			1	79	71			29 / 89	59	51	17	42	13 / 85	269	208	80	186	16 / 282
32	4	2	2	263	272	264	266	253 / 276	199	217	198	205	153 / 226	827	837	848	837	785 / 865
33			3	249	245	238	244	229 / 261	192	191	186	190	185 / 194	875	878	820	858	800 / 910
34			1	240				190 / 249	166	169	181	172	151 / 184	928	912	767	869	575 / 975
35		3	2	252	253	234	246	223 / 259	220	214	181	205	173 / 228	990	987	873	950	830 / 1010
36			3	258				238 / 266	203	212	201	205	184 / 236	972	970	923	955	910 / 1025
37			1	302	283	228	271	221 / 311	202	185	172	186	170 / 207	768	695	620	694	610 / 785
38		1	2	275	270	246	264	241 / 300	184	177	174	178	169 / 185	693	660	618	657	590 / 705
39			3	233	222	200	218	196 / 258	145	145	133	141	128 / 154	475	530	507	504	465 / 530
40			1	368	369	340	359	325 / 376	260	239	236	245	225 / 270	975	932	923	943	880 / 975
41	5	2	2	379	352	335	355	317 / 386	228	215	216	220	211 / 231	827	805	817	816	785 / 885
42			3	324	306	277	302	268 / 364	175	163	163	167	156 / 185	602	598	597	599	545 / 670
43			1	254	248	240	247	236 / 256	172	180	173	175	165 / 187	748	740	705	731	705 / 785
44		3	2	277	239	228	248	207 / 285	177	164	155	165	152 / 179	657	625	565	616	560 / 670
45			3	237	208	182	209	171 / 248	125	117	103	115	100 / 127	442	410	378	410	350 / 480
NO. OF SPECIMENS TESTED FROM EACH MIX				3	3	3	9	9	3	3	3	9	9	3	3	3	9	9

* First line : instead of 173, read 1173.

TABLE 2

TEST DATA FOR JOINT STRENGTH

				JOINTING CONCRETE						JOINTING STEEL
TYPE OF SPECIMENS JOINTED				100 MM φ x 50MM CYLINDERS, 5 MM MORTAR JOINT.				40 MM x 100 MM x 250 MM REINFORCED BEAMS, 5 MM MORTAR JOINT.	70,7 MM x 70,7 MM CUBES, 5 MM MORTAR JOINTS.	STEEL PIPE 200 MM, D_i = 28 MM D_y = 46 MM. DEFORMED STEEL BAR 20 MM KS 40.
TEST METHOD										
STRESS FORMULA				$\sigma = \frac{P}{\pi \cdot 10^2/4}$				$\sigma = \frac{P/2 \cdot 15}{1/6 \cdot 4 \cdot 10^2}$	$\sigma = \frac{P/2}{7{,}07^2}$	1. STEEL PIPE JUST PARTLY FILLED WITH MORTAR. 2. IRREG. IN ALIGNMENT OF BARS.
MIX NO.	BINDER	AGGREGATE	MIXING RATIO	JOINT IN TENSION, KP/CM² TEST SPECIMEN NO. 1	2	3	AVERAGE	JOINT IN BENDING, KP/CM²	JOINT IN SHEAR, KP/CM²	FAILURE LOAD, KP
1			1	15	13	19	16	33	41	18100
2		1	2	24	23	25	24	96	44	8500 1)
3			3	30	29	35	31	95	31	21200
4			1	20		22	21	44	27	18600
5	1	2	2	27	32	30	30	58	29	20100
6			3	28	29	30	29	80	31	19700
7			1	39	24	42	35	39	38	16600 1)
8		3	2	42	42	40	41	92	27	21700
9			3	37	39	37	38	79	32	23500
10			1	14	14	12	13	9	16	14000
11		1	2	15	17	21	18	38	13	17300
12			3	13	10	7	10	36	17	14400
13			1	2	4	3	3	48	14	
14	2	2	2	14	11	10	12	72	12	19550
15			3	18	17	15	16	20	24	17300
16			1	13	15	16	14	39	24	14400
17		3	2	13	21	16	17	61	32	14950
18			3	18	16	20	18	43	29	8000
19			1	1	1	1	1		7	9090
20		1	2	15	7	9	10	14	18	16620
21			3	17	16	15	16	14	12	4730
22			1	1	3	2	2	8	2	4200
23	3	2	2	6	5	6	6	28	15	9380
24			3	13	11	20	15	12	15	16040
25			1	5	9	7	7	15	13	7150
26		3	2	12	13	13	13	29	13	5700
27			3	14	13	11	13	18	16	300
28			1	10	4	12	9	12	3	10600 1)
29		1	2	14	17	17	16	17	5	15500
30			3	8	8	12	9	20	10	17800
31			1						1	7400 1)
32	4	2	2	6	13	8	9	9	10	19500
33			3	6	7	6	6	15	11	13400
34			1	9	5	5	6		3	14800 1) 2)
35		3	2	17	16	11	15	15	14	17700 2)
36			3	11	16	14	14	34	21	22500 2)
37			1	25	26	29	27	35	39	5000 1)
38		1	2	32	30	29	30	64	49	10500
39			3	24	27	22	24	74	60	14000
40			1	20	16	30	22	35	33	12100 1)
41	5	2	2	26	35	32	31	70	48	17300
42			3	21	22	25	23	44	50	18300
43			1	37	33	37	36	63	55	19100 1)
34		3	2	33	28	28	30	53	21	19000
45			3	27	25	21	24	72	56	13100

4. DISCUSSION

4.1. Binders.

Binder no. 1 was a research product developed especially for glueing concrete. It had the lowest viscosity of the five binders and as pointed out in [2] a binder with a low viscosity not only gives the best workability but also allows the greatest amount of filler to be added. The pot-life of mortars with type 1 binder was less than 2 hours and temperatures above 50 °C were recorded in the mortar when the binder gelled. The high reactivity of the binder enables the mortar to cure at temperatures as low as 0 °C. The high temperatures caused by the exothermic reaction can, however, cause thermal stresses when large amounts of mortar are being used, but this should be no problem for normal joint thicknesses.

Binder no. 2 is considered to have too high viscosity to be used as a binder in a mortar for jointing.

Binder no. 5 which was a modification of the no. 2 epoxy binder should yield a good binder for resin mortars for jointing, if its viscosity were lowered and its reactivity increased. Polyester binder no. 3 could similarly be modified to produce a satisfactory binder.

Polyester binder no. 4 was included in the testing program for comparative purposes because NBRI previously had been commissioned to do extensive testing on this binder for a different application. It is also considered to have too high viscosity to be used as a binder in a mortar for jointing.

4.2. Aggregates.

It was recommended by CIBA to use a quartz aggregate with gradation such as aggregate no. 2. For all types of binders, however, mortars made using the well-graded aggregates type no. 1 or 3 had for the same mixing ratio better workability than mortars made with aggregate type no. 2. This confirms the theory that the principles for choosing aggregates for conventional mortars are also valid for resin mortars [2]. The optimal mechanical properties and the best workability for most of the resin mortars tested were obtained with 80 % aggregate and 20 % binder by wt. To obtain a less expensive mortar by lowering the resin content without changing the workability and the strength properties, mortars with increased amounts of coarse material of aggregate types no. 1 and 3 will be tested.

4.3. Curing conditions.

The curing conditions did not have any significant effect on the 7-day strength of mortar specimens.

4.4. Joints.

The tests on concrete specimens showed that surface preparation by wire brushing was in most cases not satisfactory. Most manufacturers of resins recommend sandblasting and degreasing of concrete surfaces prior to jointing, this will remove the surface laitance that broke away from the aggregate in a number of tests. By using the more elaborate surface preparation recommended, the tests that indicated the strength of a resin mortar joint will be greater than that of concrete for short-term static loading.

The pull-out test showed remarkable strength of the joints for most mortar mixes, considering that the theoretical yield load for the steel bar was 12,700 kp. The resistance against pull-out of the bars arises from adhesive resistance and sliding resistance. Sliding resistance is caused by deformations on the surface of the bar and irregularities of its section and alignment. The main advantages of a double-lap shear joint of this type are: the surfaces are easily prepared, just two materials —mortar and steel—are in contact in the joint, only a small amount of mortar is needed, and it is possible to utilize fully the strength properties of the mortar.

Before the jointing technique is used in the field, extensive tests are planned on double-lap shear joints. First it is planned to test the influence on the joint strength of variable joint thicknesses and bond lengths. In [4] it is noted that there exists a fairly good correlation between the strength of glued double-lap shear joints and the ratio l/t, l being the bond length, and t, the thickness of the glue layer. It is uncertain, however, whether the proposed type of joint will act as a double-lap shear joint or just as a joint with embedded bars; this will probably depend on the joint thickness. No test data are available for bars embedded in resin mortars, but pull-out tests of bars at the University of Illinois [5] indicated that bond stress is not uniformly distributed along a bar embedded in concrete. And the joint strength did not differ significantly for bars of different diameters. The last finding will probably not apply with resin mortars which adhere strongly to steel. It is expected that adhesive resistance to pull-out of bars from resin mortars depends not only on bond length but on bond area. Another important factor to be determined by tests will be the effect of shrinkage of the mortar on the joint strength. The shrinkage of the mortar will increase with increasing binder content in the mix.

Resin mortars have already found some use in Norway for jointing prefabricated concrete columns. Steel bars 26 mm ⌀ protruding 400 mm out of the columns are fitted into 450 mm deep holes prefilled with resin mortar in the concrete foundation. One disadvantage with this jointing method appears to be that the joint strength depends both on the bond strength of mortar to steel and mortar to concrete. By extending bars into the hole from the foundation and lapping them with the column bars it should be possible to make a better joint. This and other methods for splicing reinforcing steel, as well as the tests described for pipe joints will be included in our next testing program.

4.5. Test methods.

The test methods on small mortar prisms are considered well adapted for optimizing the strength properties of mortars with good workability to be used in relatively thin layers.

As outlined in 3.3 the test methods are less adapted for mortars with low workability. Therefore it is important to try to develop a satisfactory method for measuring the workability of the mortar. Factors affecting the workability are gradation, shape of particles, viscosity of the binder, and proportions. It is also important for evaluating a mortar to measure the shrinkage of the mortar.

The tensile bond strength test on concrete cylinders is considered satisfactory, but a better shear test method must be developed. To obtain reproducible results, proper surface preparation of the concrete specimens must be achieved. The cleavage test by flexural bending of jointed concrete beams will be dropped from future testing programs because it is felt that this test gives little additional information about the joint strength to add to that obtained with the tensile bond strength test.

The simple pull-out test of bars is considered satisfactory.

CONCLUSIONS

The tests described in this paper were preliminary and the main purposes with the tests were to establish testing methods for evaluation of resin mortars as a jointing material, to compare different resin mortars, and to test methods for jointing.

The test methods for small resin mortar specimens are considered advantageous for optimizing the strength properties of mortars, to be used in relatively thin layers. In future tests, methods for measuring workability and shrinkage of the mortar must be adopted.

Binder no. 1 with its high reactivity and low viscosity yielded mortars with the highest strength. Aggregates type no. 1 and 3 produced mortars with better workability than aggregate type no. 2. The best workability for the mortars were obtained with 20 % binder by wt in proportion of the mix. The curing conditions did not have any significant effect on the 7 day strength of mortar specimens.

The tensile bond strength test on concrete cylinders is useful where the limited tensile strength of concrete has to be taken into account in design. To get reproducible results the concrete surfaces to be jointed must be properly prepared. It is considered that the cleavage test gives little additional information about the joint strength to add to that obtained with the tensile bond strength test. The shear bond test method proved to be unsatisfactory.

By further testing of the pipe joint and other methods for jointing reinforcing steel it should be possible to find practical solutions for jointing steel bars with resin mortars.

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